HANDBOOK

of

LOCK BAR STEEL PIPE

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EASTPORT STEEL PIPE COMPANY

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HANDBOOK

of

LOCK-BAR STEEL PIPE

Compiled by

EAST JERSEY PIPE COMPANY

7 Dey St., New York

1930

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EAST JERSEY PIPE COMPANY
7 Dey St., New York City

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EAST JERSEY PIPE COMPANY

Manufacturers of

"LOCK-BAR" Steel Pipe

Riveted Steel Pipe
Special Couplings and Joints
Large Riveted Steel Tees, Reducers and Specials
Fittings of Every Character

GENERAL OFFICES
7 Dey Street
New York, N. Y.

WORKS
Leetsdale
Pennsylvania

Associated with
T. A. GILLESPIE COMPANY
Engineers and Contractors

7 Dey Street
New York City

18565

Leetsdale
Pennsylvania

Foreword

The ever increasing demand for additional water, gas and oil pipe lines throughout the country, together with the real need for a simplified engineering exposition of the broad subject of steel pipe, years ago impelled this company to depart from its former practice of merely cataloguing briefly the merits of the products it manufactures, and to issue in convenient form, for the guidance of the non-technical public official, and the use of the field and office engineer, a Handbook of Pipe.

This edition, published 10 years after its predecessor, is justified because of the remarkable advance in the use of steel pipe during the past decade, and the greater clarity in understanding with regard to the advantages of steel over pipes of other character.

Certain subjects closely related to the use of pipe have been incorporated in this handbook. These refer particularly to such general information and engineering data as are germane to the theme under discussion. In compilations of engineering data, only the works of competent and widely recognized engineers have been selected, and wherever use has been made of such material due credit has been justly given.

A generation ago the use of steel pipe was often questioned as of doubtful expediency. That the objectors were honestly mistaken has been proved by experience. The art of steel manufacture has advanced to a point of practical perfection. Greater metal purity, better fabrication, improved laying procedures and superior coatings, have contributed to establish the superserviceability of steel pipe as regards length of normal life and stability in unfavorable environment.

Our Silver Anniversary

The year 1930 recorded the SILVER ANNIVERSARY of the use of LOCK-BAR Steel Pipe in America. Twenty-five years ago, in 1905, our company installed four miles of 43- to 48-inch LOCK-BAR pipe in Wilmington, Delaware. This

marked the beginning of what became a stupendous enterprise. To date hundreds of miles of LOCK-BAR Steel Pipe have been laid in the States of Alabama, California, Colorado, Delaware, District of Columbia, Florida, Indiana, Massachusetts, Michigan, Minnesota, Missouri, Montana, Nebraska, New Jersey, New York, Ohio, Oregon, Pennsylvania, Utah, Vermont, Virginia and Washington, the territories of Alaska and Hawaii, the Canadian Provinces of New Brunswick, Quebec, Ontario, Manitoba and British Columbia, and the Republic of Cuba.

It is hoped, and confidently believed, that this "Handbook" will be of considerable service to those interested in the subject matter; and this Company derives no small measure of satisfaction in presenting it with its compliments.

Superiority of Lock-Bar Steel Pipe

It is not an experiment.

Hundreds of miles of it are giving excellent service.

Steel pipe does not break; it bends and dents, where other pipe breaks, under adverse conditions.

It is lower in first cost.

It is stronger than other pipe, and therefore more reliable.

Its joints are as strong as the pipe itself.

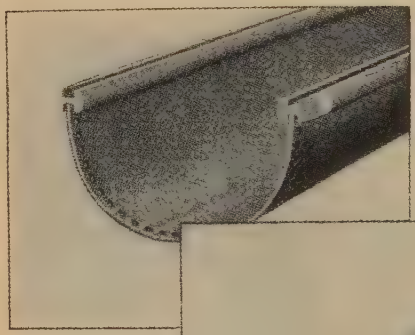
Leakage is at a minimum.

It can be installed and repaired more quickly than any other type of pipe.

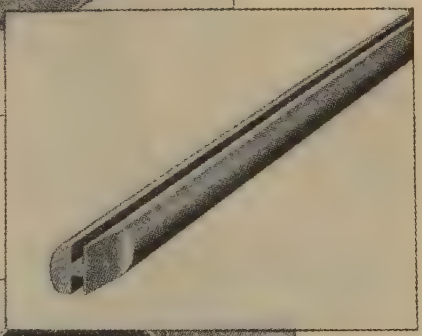
Greater water carrying capacity for the same unit diameter of pipe.

Drilling Plates

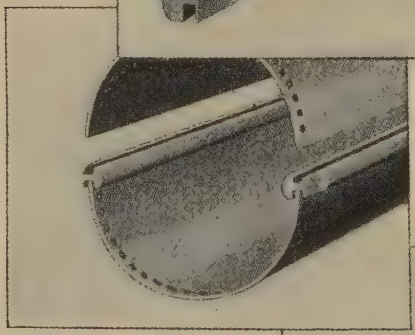
Fabricating



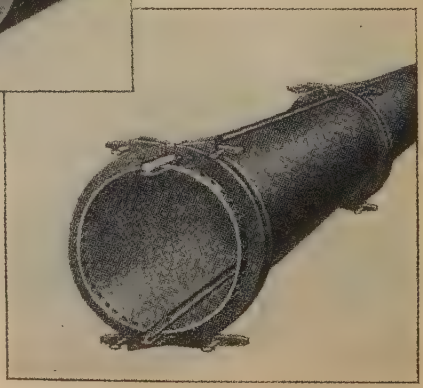
Applying
The "Lock-Bars."



Scarfed
"Lock-Bar"

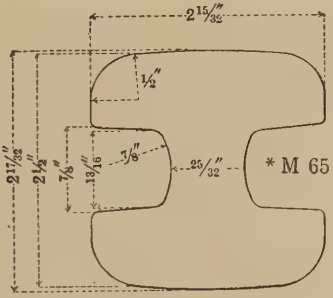


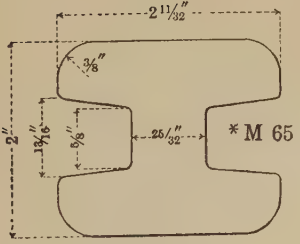
Assembling
Halves

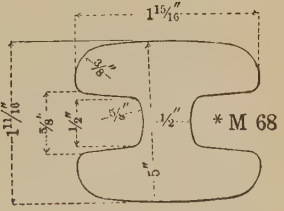


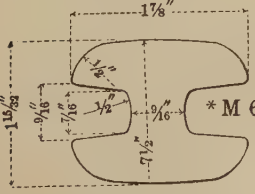
Clamping
Before
Pressing

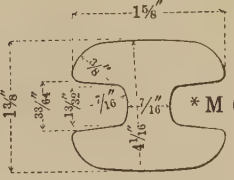
Lock-Bar Sections and Dimensions









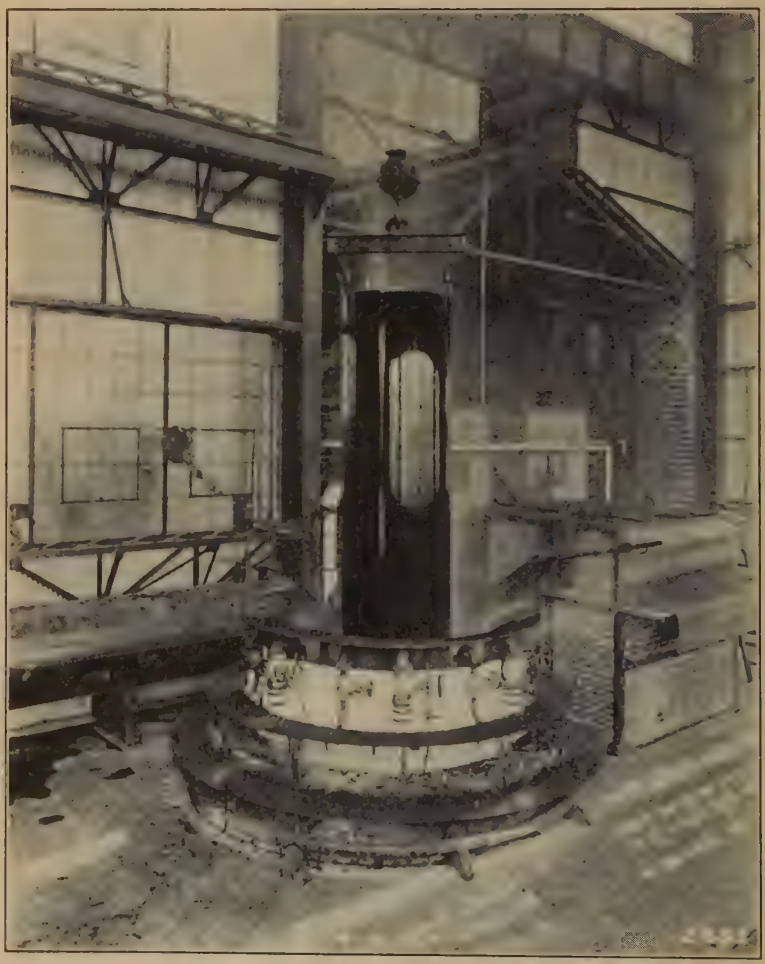


Section Index	Nominal Size	Depth, Inches	Width, Inches	Web Thickness, Inches	Weight per Foot, Pounds
*M 65c	7/16	2 17/32	2 15/32	25/32	15.9
*M 65	3/8	2	2 11/32	25/32	12.0
*M 68	5/16	1 11/16	1 15/16	1/2	8.2
*M 67	1/4	1 15/32	1 7/8	9/16	6.5
*M 61	3/16	1 3/8	1 5/8	7/16	5.3

*Furnished only by special arrangement.

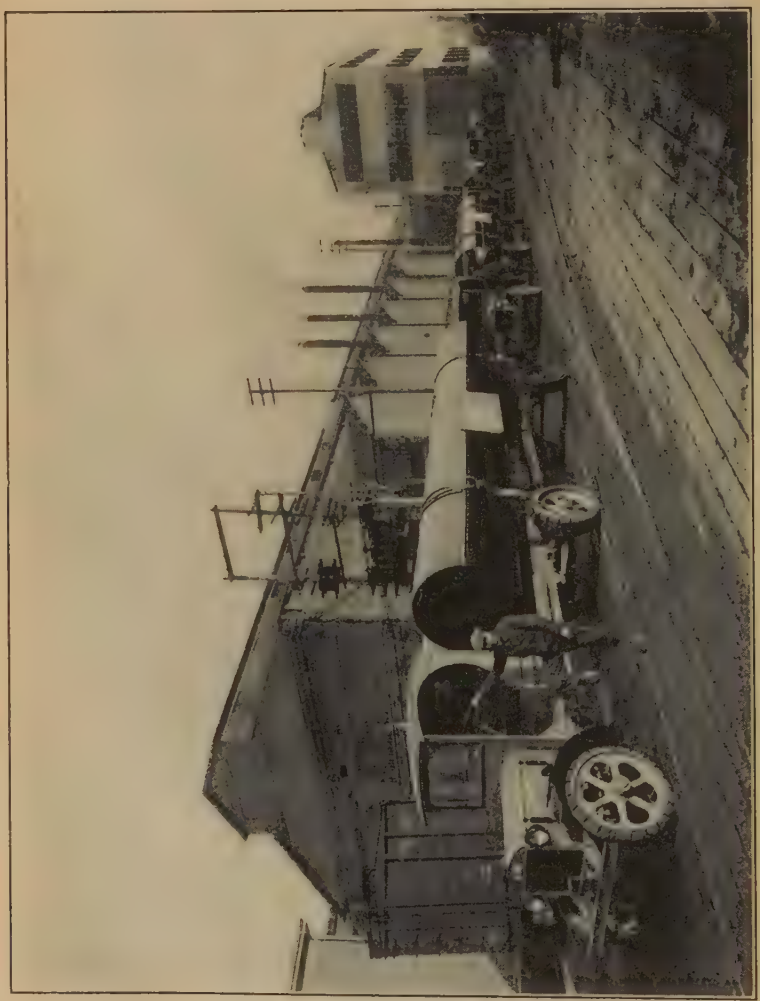
Pressing the Longitudinal Lock-Bar Joint

Testing Lock-Bar Pipe

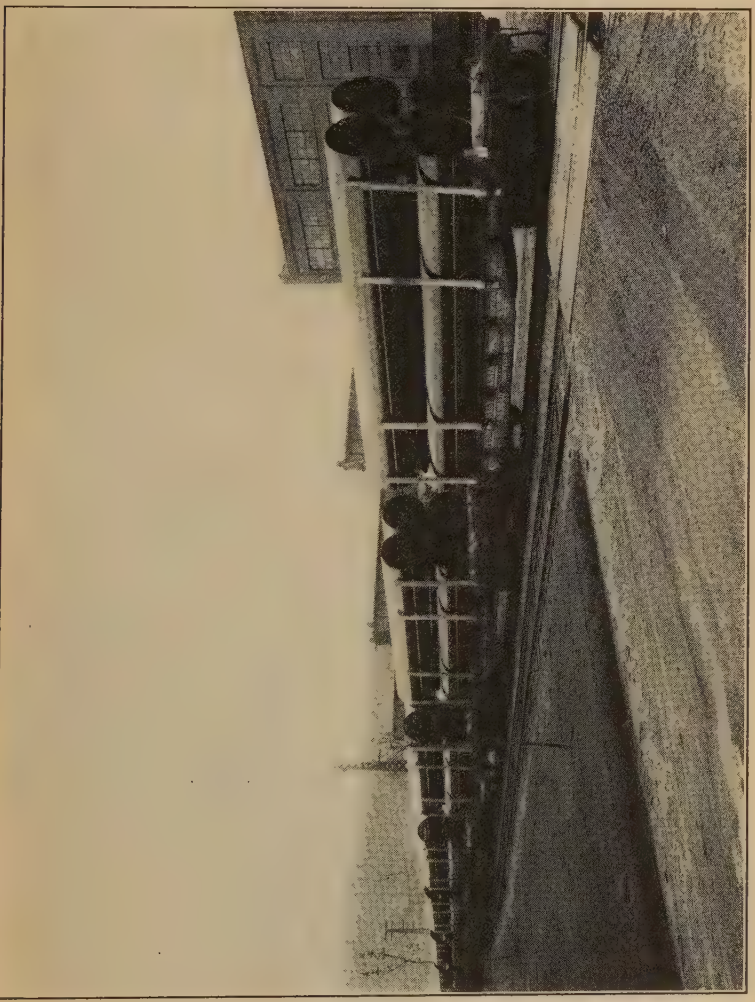


Vertically Dipping Lock-Bar Pipe

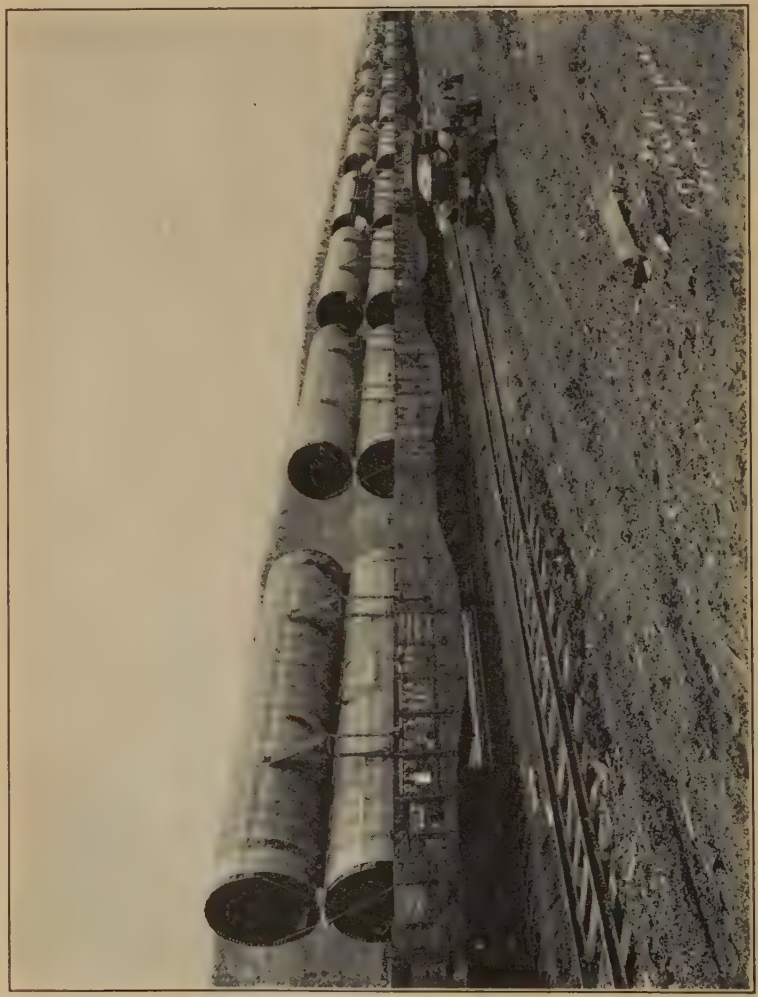
Lock-Bar Pipe Cooling After Dipping



Transporting Lock-Bar Pipe by Motor Truck



Transporting Lock-Bar Pipe by Rail



Transportation of Wrapped Lock-Bar Pipe by Rail

EAST JERSEY PIPE COMPANY

Seven Dey Street
NEW YORK, N. Y.

Product

LOCK-BAR STEEL PIPE and APPURTENANCES.

Advantages of Lock-Bar Steel Pipe

The relative advantages of different forms of pipe are determined by comparing their carrying capacities, strength, durability, and cost.

Because of its smooth interior, lock-bar pipe has a carrying capacity 15% to 20% greater than other types of pipe. It has a strength at the joint of 100%, or equal to the plate itself, as hereinafter shown.

Its reliability and relatively small cost have been amply demonstrated by actual use for many years.

Description of Lock-Bar Steel Pipe

"Lock-bar steel pipe is made by up-setting the edges of the plates and connecting them by a lock-bar in the shape of an H going over the opposite edges and being forced down over them by hydraulic pressure. This takes the place of the

Before Closing — After Closing

Lock-Bar Joint

riveting in the longitudinal joints. The circular joints may be made by riveting or otherwise, as for riveted pipe. While double riveting develops only about 72% of the strength of the steel plate, the lock-bar actually develops 100%."—*American Civil Engineers Hand Book, p. 959.*

Lengths

Standard lengths, except where necessary to fit pipe to plan or profile of line, or where sizes of plates obtainable impose other limitations, are 30-foot laying lengths, the most economical for handling and transporting.

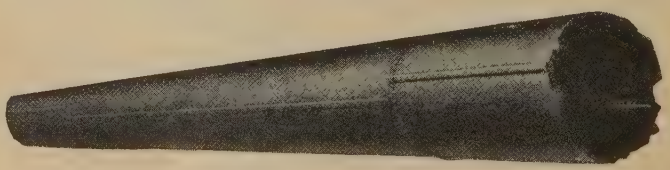
Joints

In all sizes above 24 inches, where diameter is sufficient to permit inside rivet insertion and calking, riveted taper joints (Fig. 3) are employed. For this joint the pipe is made sufficiently tapered to permit insertion of one pipe in the slightly enlarged end of the contiguous pipe, the two pipes being connected in ordinary practice by one row of rivets, after which the joint is calked both inside and outside in a manner similar to the seams of a boiler.

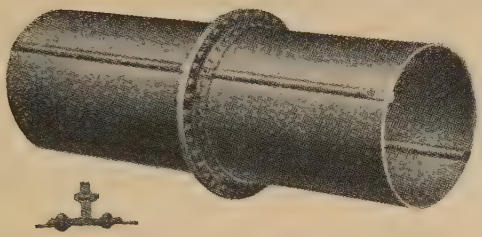
In some instances buttstrap joints are employed.

Special attention is called to the new high pressure coupling and also the modification of this coupling for submarine work. Lock-bar pipe with plain ends is furnished for use with these couplings, which can be furnished in all sizes 20 to 48 inches diameter. The lock-bar on the outside of the pipe is cut down and the pipe welded and smoothed a sufficient distance from the end to permit the pipe to fit into the coupling.

Riveted Taper Joint

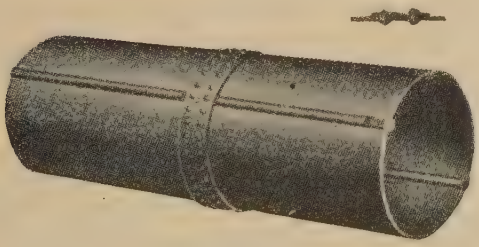


Lock-Bar Steel Pipe



Flange Joint

Flanges are rolled or cast steel. These joints are suitable for both high and low pressure service. They are furnished riveted onto pipe ends, ready for connecting.



Butt Strap Joint

Butt Strap Joints are sometimes furnished to meet peculiar conditions of installation.

Manufacture of Lock-Bar Steel Pipe From Raw Material to Finished Product

While to many users the construction and manufacture of steel pipe is perhaps no secret, yet there are many novel processes involved in the manufacture of LOCK-BAR STEEL PIPE which are of peculiar interest and are more or less unknown.

It is for this reason that a brief, non-technical description is given herewith. (See footnote*)

MATERIAL COVERED. This description covers three classes of material, namely: plates, lock-bars and rivet steel.

PROCESS. The steel is made by the open-hearth process.

DISCARD. A sufficient discard is made from each ingot to insure sound material.

CHEMICAL AND PHYSICAL PROPERTIES.

(a) The steel conforms to the following requirements as to chemical and physical properties:

Properties Considered	Plates	Lock-Bars	Rivet Steel
Phosphorus	.04	.04	.04
Sulphur	.05	.05	.045
Yield Point, Min. lb. per sq. in	0.5 T. S.	0.5 T. S.	0.5 T. S.
Tensile Strength, Min. lb. per sq. in	55/65000	40/50000	46/56000
Elongation	1,500,000	1,500,000	1,500,000

(b) The yield is determined by the drop of the beam of the testing machine.

LADLE ANALYSES. An analysis of each melt of steel is made by us to determine the percentage of carbon, manganese, phosphorus and sulphur. This analysis is made from a test ingot

*For the convenience of the reader, there is reproduced on page 91 et seq. of this Handbook a set of detailed specifications covering the manufacture, fabrication, testing and laying of Lock-Bar Steel Pipe, prepared by George A. Johnson, Consulting Engineer of New York, for the North Jersey District Water Supply Commission.

taken during the pouring of the melt. The chemical composition thus determined conforms to the requirements specified in above table, and is reported to the purchaser or his representative if requested.

Check Analyses. Analyses may be made by the purchaser from finished material representing each melt. The phosphorus and sulphur content thus determined will not exceed that specified in above table by more than 25%.

Modifications in Elongation.

(a) For plates over ¾-in. thick, a deduction of 1 from the percentage of elongation specified in above table is made for each increase of ⅛-in. thickness above ¾ inch.

(b) For plates under 5/16-in. thick, a deduction of 2.5 from the percentage of elongation specified in above table is made for each decrease of 1/16-in. thickness below ⅝ inch.

Bend Tests.

(a) The test specimens for plates are bent cold through 180° without cracking on the outside of the bent portion, as follows:

For material ¾-in. or under in thickness, flat on itself; for material over ¾-in. thick, around a pin the diameter of which is equal to the thickness of the specimen.

(b) The test specimen for LOCK-BAR bars and rivet steel is bent cold through 180° flat on itself without cracking on the outside of the bent portion.

Test Specimens.

(a) Tension and bend test specimens are taken from rolled steel in the condition in which it comes from the rolls and is of the full thickness or diameter of material as rolled except as specified in Paragraph (c).

(b) Tension and bend test specimens for plates may be machined to the form and dimensions shown herewith or with both edges parallel.

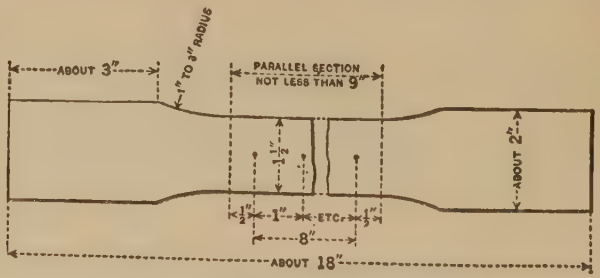
(c) Tension and bend test specimens for lock-bars may be machined to a rectangular section.

NUMBER OF TESTS.

(a) One tension and one bend test are made from each melt; except that if material from one melt differs $\frac{3}{8}$-in. or more in thickness, one tension and one bend test are made from both the thickest and the thinnest material rolled.

(b) If any test specimen shows defective machining or develops flaws, it is discarded and another specimen substituted.

(c) If the percentage of elongation of any tension test specimen is less than that specified in above table, and any part of the fracture is outside the middle third of the gauge



length, as indicated by scribe scratches marked on the specimen before testing, a retest is made.

PERMISSIBLE VARIATIONS. The thickness of each plate will not vary under the gauge specified more than 0.01 inch. The over weight will be within the limits adopted by The Association of American Steel Manufacturers for plates ordered to gauge.

FINISH. The finished material will be free from injurious defects and will have a workmanlike finish.

MARKING. The melt number will be legibly stamped on all finished material, except that rivet steel and LOCK-BAR bars may be shipped in securely fastened bundles with the melt number legibly stamped on attached metal tags. The melt number will be legibly marked, by stamping if practicable, on each test specimen.

INSPECTION. The Inspector representing the purchaser will have free entry at all times while work on the contract of

the purchaser is being performed, to all parts of the manufacturer's works which concern the manufacture of the material ordered. The manufacturer will afford the inspector, free of cost, all reasonable facilities to satisfy him that the material is being furnished in accordance with specifications. All tests (except check analyses) and inspection will be made at the place of manufacture prior to shipment, unless otherwise specified, and be so conducted as not to interfere unnecessarily with the operation of the works.

Fabricating. The steel plates are delivered to the shop where they travel in progressive method of manufacture, from machine to machine, each designed to perform a particular part of the work in a manner that insures within the machine itself exact conformity to the specification requirements.

Planing and Up-Setting. The design of LOCK-BAR PIPE requires that the longitudinal edges of the plates shall be planed to the proper dimensions and the edges up-set to a sufficient degree to form the necessary shoulder for engaging the lock-bar.

The steel plate 30 ft. long, except where necessary to fit pipe to plan and profile of line, after passing inspection, is delivered to the planing and up-setting machine, and each longitudinal edge planed and up-set by a traveling carriage equipped with cutter and up-setting rolls, while being held fixedly in position by a hydraulic clamp running the full length of the machine.

When the plate leaves the planing and up-setting machine it is of taper section, to provide for taper joint laying.

Before proceeding further the edges are tested by gauging for up-set.

Truing, Punching and Beveling. The plate, or multiples thereof, is then laid out for truing, punching and beveling on the ends, passing to the drilling machine. It is trued and then punched by sharp, clean punches and dies, leaving clean holes without burrs.

From here it passes to a machine where the ends are bevel-sheared for caulking purposes in laying, the bevel on each end being on opposite sides of the plate.

Crimping and Rolling. The plate passes to the crimping machine, where the longitudinal edges are crimped to the proper radius preparatory to rolling. The crimping is done so as to eliminate damage to the up-set edges in the rolls.

The plate is next cold rolled to the radius of the cylinder of the pipe.

Assembling. Assembling then begins, in pits arranged to accommodate, passing through the several stages as follows: Applying the lock-bars, previously scarf milled at opposite ends; lowering mate-half into lock-bar; drawing up the several sections by means of heavy steel clamps.

The assembled pipe is now ready for the final fabricating process. It passes into the pressing machine, where both lock-bars are pressed down over the up-set edges of the plates by a hydraulic press, exerting a pressure of 350 tons per lineal foot of pipe.

Testing. The pipe is now ready for testing. It is conveyed to the hydraulic testing machine, and subjected to a test 1½ times the working pressure, undergoing a rigid inspection for leakage over the entire length of the lock-bar joints.

Coating Pipe. Each length of pipe is thoroughly cleaned, all loose scale, rust, grease, and dirt being removed. It then passes to the coating room where it is heated in an oven to a temperature of 425° F. Upon removal the pipe is then immersed in a vertical dipping tank containing a bath of specially prepared coating, which is also maintained at the correct temperature for dipping. This bath is deep enough to permit entire vertical submergence of the pipe. It receives a strongly adhering coating, 1/32 inch or more in thickness, free from blisters and bubbles. This coating after setting will not become soft enough to flow at a temperature of 150° F., nor brittle enough to crack or scale off in freezing temperature.

After the pipe sections have been removed from the bath, they are set in vertical position for cooling, and when the coating has become hard are ready for loading.

Every engineer having to do with pipe lines knows that they should be protected against corrosion, inside and out.

LOCK-BAR Steel Pipe is dipped vertically into a bath of specially prepared pipe-coating which embodies all the qualities that long experience in this field has shown to be essential.

This coating is proof against the corrosive action of ground water and of the acids and alkalis of the soil, and has the mechanical properties—toughness, tenacity and pliability—that are required to resist the abrasion and other abuse to which pipe is subject in handling and laying.

It is unaffected by the extremes of atmospheric temperature. It will neither crack and crocodile under the cold of winter, nor soften and run under the hottest summer sun. Throughout this entire range of temperature its consistency remains practically unchanged, and its sturdy toughness is as much in evidence at one extreme as at the other.

Such a coating makes for economy in two ways. Not only does it prolong the life of the pipe, but it also prevents the formation of tubercles and the resulting loss in carrying capacity. Taken together with the unobstructed cross-section and the smooth interior surface that are distinctive features of LOCK-BAR PIPE, this brings about a greater carrying capacity throughout the entire life of the pipe and insures the maximum of pipe-line efficiency.

Installation of Large Steel Pipes

Transportation. Pipe is unloaded from the cars by any convenient equipment such as a locomotive crane, derrick, yard gantry or other apparatus, or it can be unloaded by hand by snubbing it with a preventer line and rolling it down inclined skids, or it can be hauled or lowered by the aid of teams.

Distribution along the pipe line is governed largely by the topography of the country, the length of the line, the size of the pipe and the facilities convenient. For a large amount of heavy pipe in a tolerably level country, it pays to construct a narrow gauge service track and haul the pipe with dinky locomotives.

For short lines or very light pipe, delivery can be made by automobile trucks or trucks and trailers, or the pipe can be loaded directly on timber sleds or on pole wagons according to topographical and weather conditions. It is distributed close to the line of trench and securely blocked to prevent it from

rolling down hill. Generally it is more convenient to handle when laid parallel with the trench, but when the topography does not permit this arrangement it may be placed at a skew or at right angles to the axis of the trench. In any case it can be slewed, rolled or snubbed into position for finally lowering into the trench, due care being given to protection of the coating.

Trench Excavation. The trench is usually made with a clear width of 12 to 18 in. more than the diameter of the pipe, and deep enough to provide at least 2 ft. of cover over the top of the pipe. This amount of earth is considered necessary for adequate protection from loads and impact, exclusive of protection required from frost.

In very rough or stony country it may be necessary to make the excavation by hand or with scrapers and teams, but the latter method necessitates sloping banks. In shale, hardpan or rock, drilling with compressed air machines and blasting are generally necessary, although soft or rotten rock and hard strata may sometimes be excavated by steam shovels without blasting.

When the amount of work, character of the soil and the topography permit, it generally makes for greater speed and economy to excavate with a trench machine or a light revolving steam shovel with a long boom and bucket.

When the revolving steam shovel is used, it travels over the excavated trench supported on timber mats spanning the trench that are taken up in the rear and laid down in advance by the shovel itself as it progresses. The use of the steam shovel for excavation is of advantage in that it permits the separation of the soil into waste and into suitable backfilling material.

In order to accommodate or rivet and caulk the transverse field joints 30 ft. apart, bell holes 4 ft. long and 1 ft. deep are dug at the bottom of the trench and between them the bottom is carefully levelled to uniform grade to support the pipe continuously.

Lowering and Assembling. The pipe trench is spanned by transverse wooden skids on which the pipe is rolled in a position directly above the centre line of the trench and with the rear end of the section just over the forward end of the last assembled section. One or two stiffleg derricks are set opposite

the pipe section on the side of the trench, or a pair of tripods with hand crabs operating manila tackles are set up over the pipe, one near each end, manila rope slings are placed around the pipe and engage the tackles, the pipe is hoisted slightly, skids removed, and the pipe lowered to approximate position on the bottom of the trench.

When the pipe is intended for riveted transverse circular field joints, the rear end of the last section is entered in the forward end of the preceding section by means of steel spud bars flattened on one end and pointed on the other end. The flat end is used as a wedge for entering the pipe, and the pointed end as a drift to engage the open rivet holes and pull them to registration. The bars are made a few inches shorter than the pipe diameter so that they may have clearance for operation inside the pipe. When the rivet holes register they are service bolted and matched with a few additional drift pins to prevent the possibility of displacement by creeping, expansion or contraction, or by disturbances in assembling the next section. When necessary the entrance of one pipe into the next may be promoted by a longitudinal pull and hoist with the derrick.

For a pipe of medium size, say 40 in. in diameter, the normal pipe laying gang consists of about 25 to 35 men who roll the pipe on the skids, bring up and set the derricks, enter the pipe sections, and bolt up the joints.

With field riveted joints, vertical and horizontal angles up to a deflection of three degrees can be made with standard sections entered in tangent alignment and then forced into transverse positions corresponding to the spacing of the rivet holes carefully located to conform with the required deflection.

Riveting. The five-man riveting gang removes the temporary joint bolts, lays up the steel plate tightly with an iron maul, and bolts the pipe securely with sufficient bolts to hold the sheets tight for reaming and riveting. Riveting is usually done by pneumatic tools, operated on the outside except for the bottom half of the circumference where riveting is usually done from the inside.

Rivets are heated in hand blast coal furnaces on the surface of the ground adjacent to the pipe joints, and are delivered to the interior of the pipe through drop holes 2 in. in diameter

that are provided for that purpose on the upper side of the pipe at every joint and are afterwards closed with screw plugs.

On long lines or where the work is subject to delay or interruption at special points, the pipe is assembled sometimes in sections commenced at different points and eventually joined to each other by special closures. After the joints are riveted they are painted with a special preservative paint. Extended use is made of the patented high pressure flexible couplings for transverse field joints with lock-bar pipe for gas lines, and on diameters of 24 in. and on under water lines where the pipe is too small to permit working on the inside.

After the field joints are completed the pipe is tested in convenient lengths of from 1 to 4 miles by pneumatic pressure for gas mains and in lengths of from ½ to 2 miles by hydraulic pressure for water mains to a required pressure, usually 50% in excess of the normal working pressure contemplated.

Elevated and Submerged Pipes. When it is desirable to elevate pipe, concrete piers spaced about 30 ft. apart are generally used. On short trestles the pipe sections may often be most advantageously distributed on the surface of the ground, and successively lifted to position by derricks or locomotive cranes.

On long trestles it is generally desirable to provide a service track alongside for the delivery of the pipes. Usually one of the track stringers is laid directly on the pier tops alongside of the pipe, and the opposite stringer is supported on a single vertical falsework post braced to the concrete pier. The saddle tops of the piers are spanned by skids on which the pipes are delivered. Afterwards the pipes are raised, skids removed, and the pipes lowered to position on the piers where they are assembled and riveted in the same manner as in trenches.

Submerged pipe is always laid in a protecting trench which, when the conditions will permit, is generally most advantageously excavated by a hydraulic dredge. If the bottom is of rock or other hard stratum the excavation is usually done with a dipper dredge. Submerged pipe should be provided with flexible joints, and can generally be floated to the site in 100 or 150 ft. lengths closed with temporary bulkheads. They are sunk to the bottom by admitting water and the successive sections are connected up by divers making the bolted joints.

Sometimes the pipes are sunk between guide piles, and sometimes special equipment for floating, sinking and connecting them is devised and installed to correspond with conditions and requirements.

Submerged pipe trenches are usually backfilled to a depth of about 2 ft., and when they are exposed to wave action the covering is protected by rip rap.

Pipe Line Testing Precautions. Special precautions should be taken before placing hydraulic pressure tests on a steel pipe line after the same has been laid in a trench, prior to placing line in service.

1. See that all pipe line centers are properly backfilled and the line is thus weighted down to prevent floating.
2. All test heads or gate valves should be securely braced.
3. All blow-off valves should be closed.
4. All automatic air valves should be in position and in proper working order, with the control gate valves wide open.
5. No section of pipe should be tested without having at least one automatic air valve installed and in proper working order, even though the same may not be required for permanent operation.

Data and Tabulations Relative to Steel Pipe

In the following pages certain useful information is presented in tabular form on pipe weights according to diameter and thickness of plate, permissible variations in weights, etc., and illustrated comments on pipe, fabrication, pipe coating, joints of various types, pipe fittings, field test heads, etc. Beyond are working pressure tables, tabular data on the strength of LOCK-BAR and riveted pipe joints, the shearing and bearing value of rivets, etc.

Thickness and Weight of Pipe

Steel Pipe, either Riveted or LOCK-BAR, within ordinary limits can be made of any required diameter. In this respect it differs from cast-iron pipe, which is commonly made only of the sizes for which the foundries have molds. The diameter should always be specified as the smallest diameter of the smallest ring, where the rings are not all of the same size.

Weight of Steel Pipe. The finished weight of steel pipe per lineal foot, either Riveted or LOCK-BAR, including the excess weight of plates rolled so that the thinnest points in the plate will be approximately of the nominal thickness, and including the laps, rivets and lock-bars, material on the joints and coating, may be found approximately by the formula:

Weight in lbs. per foot $= (12.5 \times \text{diameter} \times \text{thickness}) + 10$ lbs. in which diameter and thickness are to be taken in inches. The weights of commonly used sizes are given in the tables on pages 41 and 42.

Riveted Pipe. The older lines of steel pipe prior to the introduction of LOCK-BAR and Welded, were all riveted.

General Note.

1. All weights are figured on the basis of one cubic inch of steel weighing 0.2833 pound.
2. All gross weights are figured on the basis of 30-foot lengths. We have found that lengths of pipe longer than 30 feet are less practical, and more difficult to handle, ship and lay without injury.
3. All weights given are limited to two decimal places.
4. All pipe diameter designations are inside dimensions.

Generally riveted pipe is made up of steel plates seven or eight feet wide, which are bent so that one sheet goes entirely around, forming one section of pipe. Four of these sheets are riveted together in the shop, making a length of pipe 28 to 30 feet long. This is tested for tightness and dipped in protective coating, and then shipped to the place where it is to be used.

The circular seams may be single riveted. The longitudinal seams which alone are required to carry the stress due to the pressure of the water are at least double riveted, except where the pressure is very low.

In-and-Out courses are used, alternate rings being larger and smaller. *Taper Lengths* are also used in which one end of each pipe is smaller than the other end and will slip into the large end of the next length. Pipes have also been made with all the lengths the same size, fastened together with butt straps on the outside, but as this is a more expensive method it has not been often used.

Lock-Bar Pipe. An instructive comparison of the relative weights of LOCK-BAR and double riveted steel pipe is contained in the two tables which follow. It will be noted that the latter contains slightly less metal per unit than Lock-Bar, but as has been previously pointed out, carrying capacity, number of joints, and stability factors are all greatly in favor of LOCK-BAR. These essentials must be given due consideration when comparing the relative weights of the two types of pipe.

Continuous Riveting has been used in nearly all American steel pipe lines; that is, each length in the field has been tightly riveted to its neighbor. Practical experience with this system of construction has been satisfactory.

Reference Waterworks Handbook

by

FLINN, WESTON AND BOGERT

"Plates for Steel Pipe"

Formula for thickness of double riveted pipe would work out about as follows:

"THICKNESS OF PLATE should be determined as follows:* (1) $t = pdf \div 2tsE$, t = thickness of plate, in.; p = internal pressure, lb. per sq. in.; f = factor of safety; ts = tensile strength of plate, lb. per sq. in. = (55,000); E = efficiency of joint; d = internal diameter of pipe, in. It is good practice to use 15,000 for $ts \div f$. Constant, 1/16 in., is sometimes added to computed thickness as provision against rusting.

Most shops cannot handle plates of greater thickness than 1 in.; one can take 1½ in.; 1½-in. plate in pipes costs about 25 per cent. more per lb. than 1 in., due to necessity of drilling holes after plate is rolled to cylinder, to avoid making holes oblong. Thin pipe is more expensive than medium weight, due to larger number of rivets required.

PLATE LENGTHS. Specify maximum as well as minimum lap. Edges of plates as delivered from mills are not straight; when riveted, lap is sometimes as much as 2 in. in excess."

Say 48" Diameter Pipe:

DOUBLE RIVETED

Internal Pressure = 125 lbs.
Efficiency of Joint = 65%
Tensile strength of plate, lb. per sq. in. = 55,000
Internal Diameter of pipe = 48"
Factor of safety = 4

$$t = \frac{125 \text{ lbs.} \times 48'' \times 4}{2 \times 55{,}000\# \times 65\%} = .336 \text{ inch} + 1/16'' \text{ for longevity}$$
$$= .3985 \text{ in. (Say } 3/8'' \text{ or } 7/16'' \text{ plate.)}$$

For Hammer-Welded or Lock-Bar Pipe

Efficiency of Joint = 97%

$$t = \frac{125 \text{ lbs.} \times 48'' \times 4}{2 \times 55{,}000\# \times 97\%} = .225 \text{ inch} + 1/16'' \text{ for longevity}$$
$$= .2875 \text{ in. (Say } 5/16'' \text{ plate.)}$$

(*Dept. Water Supply, Gas and Electricity, N. Y.)

Manufacturers' Standard Practice
Permissible Variations in Gauge of Sheared Plates
When Ordered to Thickness

ON CARBON STEEL PLATES, when ordered to thickness, the thickness of each plate will not vary more than 0.01 inch under that ordered. The overweight of each lot in each shipment will not exceed the amount given in the following table.

Ordered Gauge Inch	Permissible Excess in Average Weight per Square Foot of Plates for Width Given, Expressed in Percentage of Nominal Weight								
	Under 48 in.	48 in. incl. to 60 in. excl.	60 in. incl. to 72 in. excl.	72 in. incl. to 84 in. excl.	84 in. incl. to 96 in. excl.	96 in. incl. to 108 in. excl.	108 in. incl. to 120 in. excl.	120 in. incl. to 132 in. excl.	132 in. and over
Under 1/8	9	10	12	14	..	..	..	..	..
1/8 incl. to 3/16 excl.	8	9	10	12	..	..	..	..	..
3/16 " " 1/4 "	7	8	9	10	12	..	..	..	..
1/4 " " 5/16 "	6	7	8	9	10	12	14	16	19
5/16 " " 3/8 "	5	6	7	8	9	10	12	14	17
3/8 " " 7/16 "	4.5	5	6	7	8	9	10	12	15
7/16 " " 1/2 "	4	4.5	5	6	7	8	9	10	13
1/2 " " 5/8 "	3.5	4	4.5	5	6	7	8	9	11
5/8 " " 3/4 "	3	3.5	4	4.5	5	6	7	8	9
3/4 " " 1 "	2.5	3	3.5	4	4.5	5	6	7	8
1 or over	2.5	2.5	3	3.5	4	4.5	5	6	7

The term "lot" applied to this table means all of the plates of each group width and group thickness.

Manufacturers' Standard Practice
Permissible Variations in Weight of Sheared Plates When Ordered to Weight

ON CARBON STEEL PLATES, when ordered to weight per square foot the weight of each lot in each shipment will not vary from the weight ordered, more than the amount given in the following table. The weight per square foot of individual plates will not vary from the ordered weight by more than 1⅓ times the amount given.

Ordered Weight Pounds Per Square Foot	Permissible Variations in Average Weight per Square Foot of Plates for Width Given, Expressed in Percentage of Ordered Weight																	
	Under 48 in.		48 in. incl. to 60 in. excl.		60 in. incl. to 72 in. excl.		72 in. incl. to 84 in. excl.		84 in. incl. to 96 in. excl.		96 in. incl. to 108 in. excl.		108 in. incl. to 120 in. excl.		120 in. incl. to 132 in. excl.		132 in. and over	
	Over	Under	Over	Under	Over	Under	Over	Under	Over	Under	Over	Under	Over	Under	Over	Under	Over	Under
Under 5	5	3	5.5	3	6	3	7	3	...	...	...	...	...	...	...	...	...	...
5 incl. to 7.5 excl.	4.5	3	5	3	5.5	3	6	3	...	...	...	...	...	...	...	...	...	...
7.5 " " 10 "	4	3	4.5	3	5	3	5.5	3	6	3	7	3	8	3	...	...	...	...
10 " " 12.5 "	3.5	2.5	4	3	4.5	3	5	3	5.5	3	6	3	7	3	8	3	9	3
12.5 " " 15 "	3	2.5	3.5	2.5	4	3	4.5	3	5	3	5.5	3	6	3	7	3	8	3
15 " " 17.5 "	2.5	2.5	3	2.5	3.5	2.5	4	3	4.5	3	5	3	5.5	3	6	3	7	3
17.5 " " 20 "	2.5	2	2.5	2.5	3	2.5	3.5	2.5	4	3	4.5	3	5	3	5.5	3	6	3
20 " " 25 "	2	2	2.5	2	2.5	2.5	3	2.5	3.5	2.5	4	3	4.5	3	5	3	5.5	3
25 " " 30 "	2	2	2	2	2.5	2	2.5	2.5	3	2.5	3.5	3	4	3	4.5	3	5	3
30 " " 40 "	2	2	2	2	2	2	2.5	2	2.5	2.5	3	2.5	3.5	3	4	3	4.5	3
40 or over	2	2	2	2	2	2	2	2	2.5	2	2.5	2.5	3	2.5	3.5	3	4	3

The term "lot" applied to this table means all of the plates of each group width and group weight.

Weights of Steel Angles

Size in inches	Thickness in inches														
	1/8	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8	11/16	3/4	13/16	7/8	15/16	1
8 x8	....	....	....	....	....	....	26.4	29.6	32.7	35.8	38.9	42.0	45.0	48.1	51.0
7 x3½	....	....	....	....	....	15.0	17.0	19.1	21.0	23.0	24.9	26.8	28.7	30.5	32.3
6 x6	....	....	....	....	14.9	17.2	19.6	21.9	24.2	26.5	28.7	31.0	33.1	35.3	37.4
6 x4	....	....	....	....	12.3	14.3	16.2	18.1	20.0	21.8	23.6	25.4	27.2	28.9	30.6
6 x3½	....	....	....	....	11.7	13.5	15.3	17.1	18.9	20.6	22.4	24.0	25.7	27.3	28.9
5 x5	....	....	....	....	12.3	14.3	16.2	18.1	20.0	21.8	23.6	25.4	27.2	28.9	30.6
5 x4	....	....	....	....	11.0	12.8	14.5	16.2	17.8	19.5	21.1	22.7	24.2	....	....
5 x3½	....	....	....	8.7	10.4	12.0	13.6	15.2	16.8	18.3	19.8	21.3	22.7	....	....
5 x3	....	....	....	8.2	9.8	11.3	12.8	14.3	15.7	17.1	18.5	19.9	....	....	....
4½x3	....	....	....	7.7	9.1	10.6	11.9	13.3	14.7	16.0	17.3	18.5	....	....	....
4 x4	....	5.2	6.6	8.2	9.8	11.3	12.8	14.3	15.7	17.1	18.5	19.9	....	....	....
4 x3½	....	....	....	7.7	9.1	10.6	11.9	13.3	14.7	16.0	17.3	....	....	....	....
4 x3	....	....	....	7.2	8.5	9.8	11.1	12.4	13.6	14.8	16.0	17.1	....	....	....
3½x3½	....	....	5.8	7.2	8.5	9.8	11.1	12.4	13.6	14.8	16.0	17.1	....	....	....
3½x3	....	....	....	6.6	7.9	9.1	10.2	11.4	12.5	13.6	14.7	15.8	....	....	....
3½x2½	....	....	4.9	6.1	7.2	8.3	9.4	10.4	11.5	12.5	....	....	....	....	....
3¼x3¼	....	....	....	....	7.85	....	....	....	....	....	....	....	....	....	....
3¼x2	....	....	4.3	5.3	6.3	7.2	8.1	9.0	....	....	....	....	....	....	....
3 x3	2.5	3.7	4.9	6.1	7.2	8.3	9.4	10.4	11.5	....	....	....	....	....	....
3 x2½	....	3.4	4.5	5.6	6.6	7.6	8.5	9.5	....	....	....	....	....	....	....
3 x2	....	3.1	4.1	5.0	5.9	6.8	7.7	....	....	....	....	....	....	....	....
2¾x2¾	2.3	3.4	4.5	5.6	6.6	7.6	8.5	....	....	....	....	....	....	....	....
2½x2½	2.1	3.1	4.1	5.0	5.9	6.8	7.7	....	....	....	....	....	....	....	....
2½x2	....	2.8	3.7	4.5	5.3	6.1	6.8	....	....	....	....	....	....	....	....
2½x1¾	....	2.6	3.4	....	....	....	....	....	....	....	....	....	....	....	....
2½x1½	....	2.4	3.2	3.9	....	....	....	....	....	....	....	....	....	....	....
2¼x2¼	1.9	2.8	3.7	4.5	5.3	6.1	6 8	....	....	....	....	....	....	....	....
2¼x1½	....	2.3	3.0	3.7	4.4	5.0	5.6	....	....	....	....	....	....	....	....
2 x2	1.7	2.5	3.2	4.0	4.7	5.3	....	....	....	....	....	....	....	....	....
2 x1½	....	2.1	2.8	3.4	4.0	....	....	....	....	....	....	....	....	....	....
2 x1¾	....	2.1	2.7	....	....	....	....	....	....	....	....	....	....	....	....
1¾x1¾	1.4	2.2	2.8	3.4	4.0	4.6	....	....	....	....	....	....	....	....	....
1½x1½	1.3	1.8	2.4	2.9	3.4	....	....	....	....	....	....	....	....	....	....
1⅜x1	1.0	....	1.9	....	....	....	....	....	....	....	....	....	....	....	....
1⅜x ⅛	0.9	1.3	....	....	....	....	....	....	....	....	....	....	....	....	....
1¼x1¼	1.1	1.48	2.0	2.4	....	....	....	....	....	....	....	....	....	....	....
1⅛x1⅛	0.9	1.3	....	....	....	....	....	....	....	....	....	....	....	....	....
1 x1	0.8	1.2	1.5	....	....	....	....	....	....	....	....	....	....	....	....
1 x ¾	0.7	1.0	....	....	....	....	....	....	....	....	....	....	....	....	....
1 x ⅝	0.6	0.9	....	....	....	....	....	....	....	....	....	....	....	....	....
⅞x ⅞	0.7	1.0	....	....	....	....	....	....	....	....	....	....	....	....	....
¾x ¾	0.6	0.9	....	....	....	....	....	....	....	....	....	....	....	....	....
⅝x ⅝	0.5	....	....	....	....	....	....	....	....	....	....	....	....	....	....

The above weights are given in pounds per foot

Safe Working Pressure for Lock-Bar Pipe

Dia.	3/16" Lb.	1/4" Lb.	5/16" Lb.	3/8" Lb.	7/16" Lb.	Dia.	3/16" Lb.	1/4" Lb.	5/16" Lb.	3/8" Lb.	7/16" Lb.
20"	258	344	430	515	601	49"	105	140	176	210	245
21"	246	328	410	490	573	50"	103	137	172	206	240
22"	234	312	391	469	545	51"	101	135	169	202	236
23"	224	298	374	447	522	52"	99	132	165	198	231
24"	215	286	358	430	501	53"	97	130	162	194	227
25"	206	274	344	412	480	54"	96	127	159	191	223
26"	198	264	331	396	462	55"	94	125	156	188	218
27"	191	254	318	382	445	56"	92	122	153	184	214
28"	184	244	308	368	428	57"	90	120	151	180	211
29"	178	236	297	356	414	58"	89	118	148	178	207
30"	172	229	287	344	400	59"	87	116	146	175	204
31"	166	222	278	332	388	60"	86	114	143	172	200
32"	161	214	269	322	375	61"	84	112	141	169	197
33"	156	208	260	312	364	62"	83	111	139	166	194
34"	152	202	253	304	354	63"	82	109	136	164	190
35"	147	196	246	294	343	64"	80	107	134	161	188
36"	143	191	239	286	334	65"	79	106	132	158	185
37"	139	185	232	278	324	66"	78	104	130	156	182
38"	136	181	226	271	317	67"	77	102	128	153	179
39"	132	176	220	264	308	68"	76	101	126	151	177
40"	129	172	215	258	300	69"	75	100	125	149	175
41"	126	167	210	252	293	70"	73	98	123	147	171
42"	123	163	205	246	286	71"	72	97	121	145	170
43"	120	159	200	240	280	72"	72	95	119	143	167
44"	117	156	195	234	274	73"	70	94	117	140	164
45"	115	152	191	229	268	74"	70	93	116	139	162
46"	112	149	187	224	262	and					
47"	110	146	183	219	256	up-					
48"	107	143	179	214	250	wards					

$T.S.$ = 55,000 lbs.

f = 4 factor of safety

r = Radius

e = 100% eff. of joint

P = Safe working pressure

t = Thickness of plate

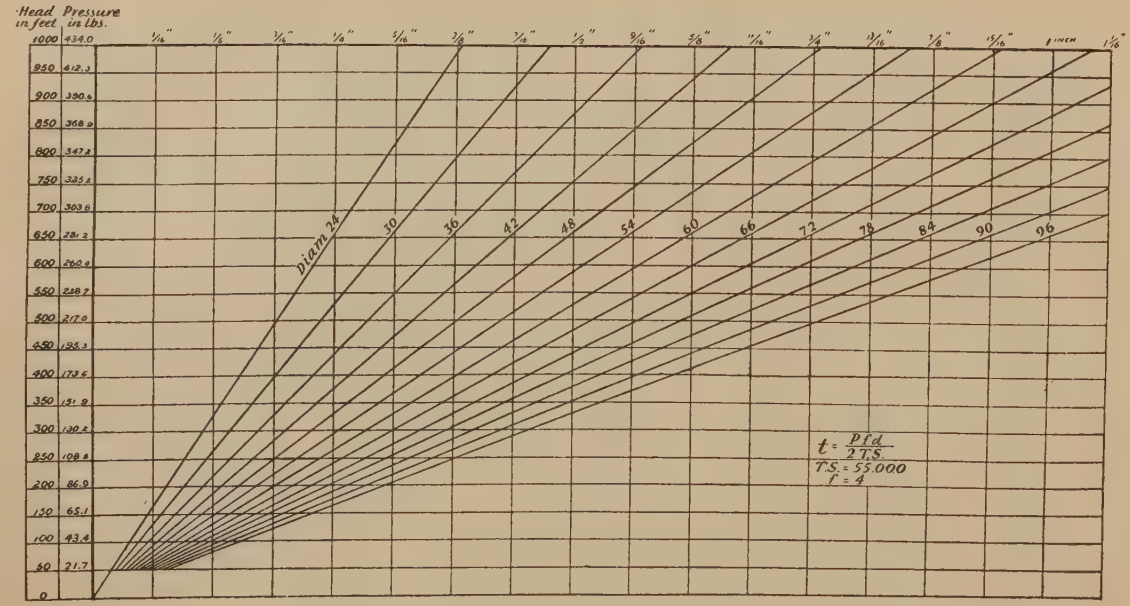
$$t = \frac{P \times r \times f}{T.S.}$$

$$P = \frac{t \times T.S.}{r \times f}$$

Safe working pressure for double riveted pipe 70% of pressure given in table.

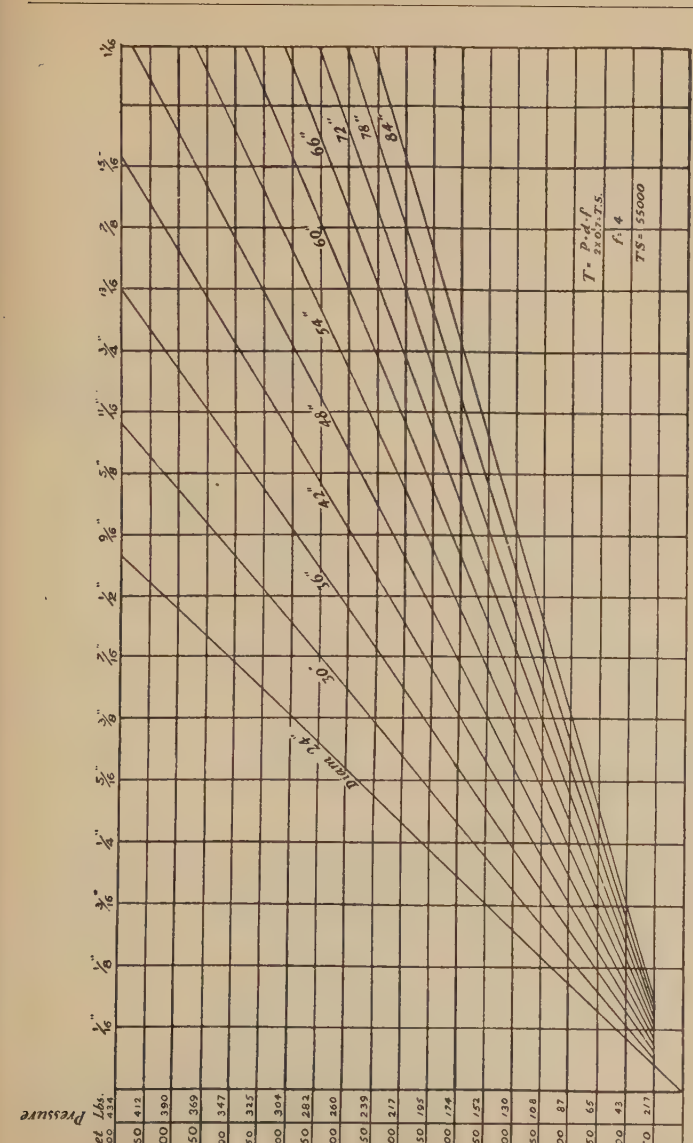
Safe Working Pressure for Riveted Pipe
70% Joint Efficiency

Dia.	3/16″ Lb.	1/4″ Lb.	5/16″ Lb.	3/8″ Lb.	7/16″ Lb.	Dia.	3/16″ Lb.	1/4″ Lb.	5/16″ Lb.	3/8″ Lb.	7/16″ Lb.
20″	180	240	300	360	420	49″	73	98	122	146	170
21″	172	230	287	343	400	50″	72	96	120	144	168
22″	163	218	271	326	380	51″	71	95	118	142	165
23″	156	208	260	312	364	52″	69	92	115	138	160
24″	150	200	250	300	350	53″	68	91	113	136	158
25″	144	192	240	288	336	54″	67	89	112	134	156
26″	139	185	232	278	324	55″	66	88	110	132	154
27″	134	178	223	268	312	56″	64	85	107	128	149
28″	129	171	215	258	300	57″	63	84	105	126	147
29″	125	167	208	250	292	58″	62	83	103	124	145
30″	120	160	200	240	280	59″	61	81	102	122	142
31″	116	155	193	232	270	60″	60	80	100	120	140
32″	113	150	188	226	264	61″	59	79	98	118	137
33″	109	145	182	218	254	62″	58	77	97	116	135
34″	106	141	176	212	247	63″	57	76	95	114	133
35″	103	137	171	206	240	64″	56	75	93	112	130
36″	100	133	167	200	234	65″	55	73	92	110	128
37″	98	130	163	196	228	66″	54	72	90	108	126
38″	95	127	158	190	222	67″	54	72	90	108	126
39″	92	123	153	184	214	68″	53	71	88	106	123
40″	90	120	150	180	210	69″	52	69	87	104	121
41″	88	117	147	176	205	70″	51	68	85	102	119
42″	86	115	143	172	200	71″	50	67	83	100	117
43″	84	112	140	168	196	72″	50	67	83	100	117
44″	82	109	136	164	191	73″	49	66	82	99	115
45″	81	108	135	162	189	74″	49	65	81	98	114
46″	78	104	130	156	182	and					
47″	77	103	128	154	180	up-					
48″	75	100	125	150	175	wards					

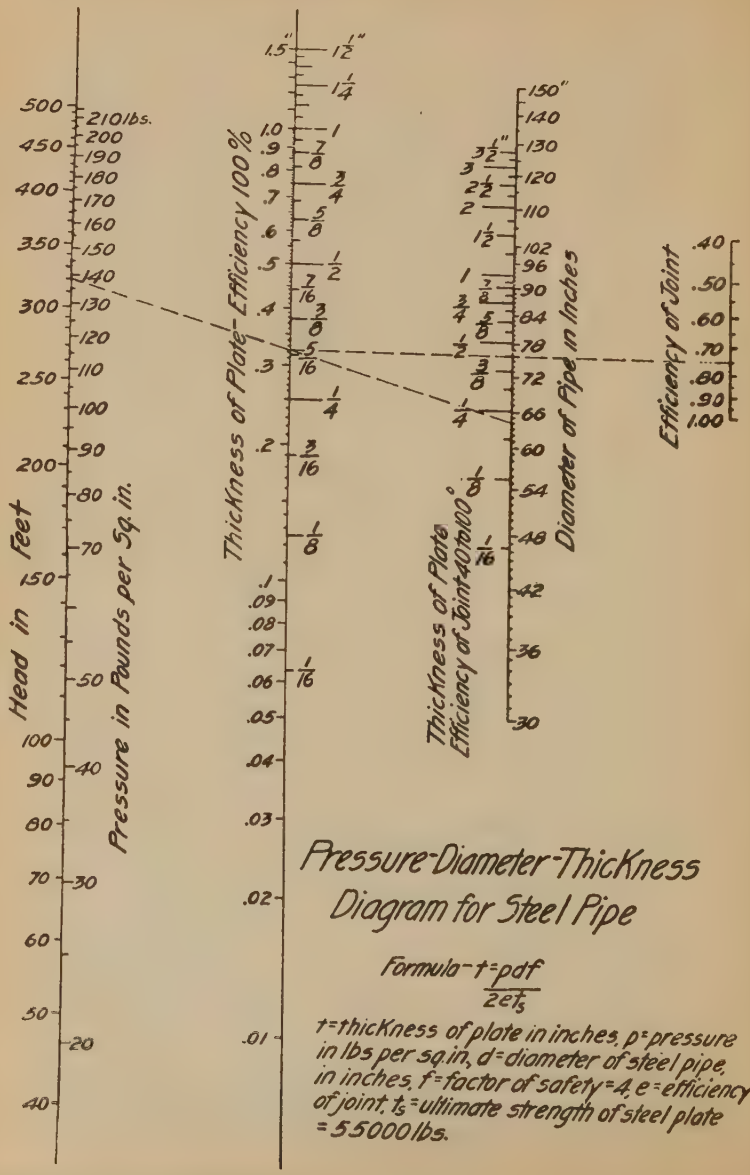


Safe Working Pressure

LOCK-BAR PIPE



Safe Working Pressure
DOUBLE RIVETED PIPE


Head in Feet
Pressure in Pounds per Sq. in.
Thickness of Plate - Efficiency 100%
Thickness of Plate Efficiency of Joint 40 to 100%
Diameter of Pipe in Inches
Efficiency of Joint
Pressure-Diameter-Thickness Diagram for Steel Pipe
Formula - $t = \frac{pdf}{2et_s}$
t = thickness of plate in inches, p = pressure in lbs per sq. in, d = diameter of steel pipe, in inches, f = factor of safety = 4, e = efficiency of joint, t_s = ultimate strength of steel plate = 55000 lbs.

Approximate Finished Weights per Foot of Double Lock-Bar Pipe

Including Plate, Lock-bars, Rivets and Coating

Diameter	3/16″	1/4″	5/16″	3/8″	7/16″	1/2″
	Lb.	Lb.	Lb.	Lb.	Lb.	Lb.
20″	57.03	74.00	91.30	113.50	137.30	150.80
22″	61.74	79.62	98.10	122.06	146.70	162.50
24″	66.46	85.24	104.85	130.60	156.00	174.40
26″	71.18	91.32	112.47	138.90	165.60	185.37
28″	75.90	97.23	119.85	147.52	175.20	196.34
30″	80.64	102.95	126.96	156.47	184.81	207.31
32″	85.11	108.87	134.38	165.11	195.22	219.27
34″	89.58	114.98	141.95	173.43	205.88	231.23
36″	94.06	121.25	149.60	181.40	216.72	243.20
38″	98.43	127.83	157.82	191.72	226.32	255.87
40″	102.80	134.19	165.45	200.67	236.94	268.54
42″	107.18	140.30	172.49	208.29	248.47	281.22
44″	112.67	147.33	181.57	218.59	259.18	291.69
46″	118.16	154.36	190.65	228.89	269.89	302.16
48″	123.67	161.40	199.72	239.20	280.60	312.60
50″	.....	168.01	206.53	248.13	290.94	324.61
52″	.....	174.62	213.34	257.06	301.28	336.62
54″	.....	181.25	220.15	266.00	311.62	348.65
56″	.....	187.52	228.78	274.97	323.24	361.93
58″	.....	193.79	237.41	283.94	334.86	375.21
60″	.....	200.05	246.05	292.90	346.50	388.50
62″	.....	208.00	254.34	307.28	357.84	401.50
64″	.....	215.95	262.63	317.60	369.18	414.50
66″	.....	223.91	270.94	323.86	380.52	427.52
68″	.....	231.19	280.23	333.83	391.68	439.52
70″	.....	238.47	289.52	343.80	402.84	451.52
72″	.....	245.76	298.81	353.76	414.00	463.53
74″ and up	.....	253.05	308.10	364.72	425.16	475.54

Approximate Finished Weights per Foot of Double Riveted Steel Pipe

Including Plate, Rivets and Coating

Diameter	3/16″	1/4″	5/16″	3/8″	7/16″	1/2″
	Lb.	Lb.	Lb.	Lb.	Lb.	Lb.
20″	52.50	70.20	89.20	108.10	125.98	145.10
22″	57.22	76.45	96.55	117.25	136.89	157.70
24″	61.95	82.70	103.90	126.40	147.80	170.30
26″	66.61	88.98	111.15	134.81	158.71	181.61
28″	71.27	95.26	118.40	143.22	169.62	192.92
30″	76.00	101.55	125.65	151.65	180.55	204.25
32″	80.90	107.73	133.23	160.66	191.53	216.00
34″	85.80	113.91	140.81	169.67	202.51	227.75
36″	90.70	120.10	148.40	178.70	213.50	239.50
38″	95.88	126.61	155.81	188.50	224.62	252.08
40″	101.06	133.12	163.22	198.30	235.71	264.66
42″	106.25	139.65	170.65	208.05	246.85	277.25
44″	111.03	145.76	179.63	217.50	256.90	289.83
46″	115.81	151.87	188.61	226.45	266.95	302.41
48″	120.60	158.00	197.60	236.40	277.00	315.00
50″	124.99	164.15	205.31	246.08	288.61	326.85
52″	129.38	170.30	213.02	255.76	300.22	338.70
54″	133.75	176.45	220.75	265.45	311.85	350.55
56″	138.46	182.86	228.13	274.56	322.63	363.76
58″	143.17	189.27	235.51	283.67	333.41	374.97
60″	147.90	195.70	242.90	292.80	344.20	387.20
62″	153.70	202.30	251.65	302.28	355.08	399.25
64″	159.50	208.90	260.40	311.76	365.96	411.30
66″	165.25	215.50	269.15	321.25	376.85	423.35
68″	171.10	222.17	277.20	330.70	387.43	435.70
70″	176.90	228.84	285.25	340.15	398.01	448.05
72″	182.70	235.50	293.30	349.60	408.60	460.40
74″ and up	188.50	242.24	301.35	359.05	419.19	472.75

Carrying Capacity of Lock-Bar Pipe

LOCK-BAR steel pipe has a smooth interior unobstructed by rivets, and has a carrying capacity somewhat greater than cast-iron pipe. Riveted steel pipes have coefficients of discharge about 20 to 25% less than equal sizes of LOCK-BAR.*

In the latter case the interior of the pipe is less smooth, the projecting rivets increasing the friction of the flowing water, as do also the numerous joints in the plates with either in-and-out joints or with taper joints. In comparing riveted pipe with LOCK-BAR pipe, the former should be taken with a sufficiently greater diameter so that its carrying capacity may be equal to that of LOCK-BAR.

It will be readily understood why LOCK-BAR pipe has so much more carrying capacity. Obstructions to flow, causing friction and reducing capacity are practically eliminated. The absence of obstruction and smooth inner surface further eliminates opportunity for the building up within the pipe of deposits to restrict the pipe area.

Cast-Iron Pipe, on the other hand, often has a rough sandy surface, and frequently presents a circular ribbed appearance due to the method of manufacture. The end joints are not always laid concentrically, and in making a "curve in the pipe" without "specials," the interior of the joints are left open on the side, top or bottom. These conditions favor the growth of organisms upon the sides and top of the pipe, and deposits upon the bottom. *Riveted pipe* is open to some extent to objections, due to the obstructions caused by rivet heads, but LOCK-BAR pipe has but one-fourth the number of circular seams that riveted pipe has and but 40% of the joints of a cast-iron pipe of 12 foot lengths. Moreover, the smooth longitudinal seams have no rivets to furnish easy attachment for foreign matter and to create eddies and the resultant friction and loss of head.

Colonel Theodore A. Leisen, in 1907 Chief Engineer of the Water Department of Wilmington, Delaware, had this to say about the carrying capacity of LOCK-BAR steel pipe:

"When the duty devolved upon us to decide on the class of pipe to be used for the mains for the extension of the water

*Water Works Practice, American Water Works Association Manual, 1925, page 291.

supply system of this city, the first question was as to the relative merits of steel and cast-iron, and this was decided purely on economical grounds, the saving to the city by the adoption of steel pipe being approximately $40,000, or 25% of the cost of cast-iron pipe.

"The second question was to decide between the ordinary riveted and the lock-bar pipe. At that time the lock-bar pipe was an innovation in this country, and, there being no precedent to follow, it was necessary to arrive at a conclusion based solely on our own judgment of the mechanical merits of the lock-bar as a serviceable joint, as compared with the usual longitudinal riveted joint, having in mind the unbroken interior surface presented by the lock-bar pipe, with the consequent reduction of friction."

"Regarding the relative carrying capacity of the lock-bar pipe with its continuously regular inside surface, and the ordinary riveted pipe with inner and outer sheet forming a break in the continuity of the surface every seven feet, it becomes self-evident that the frictional resistance of the latter will be largely in excess, and inversely the velocity and carrying capacity of the lock-bar pipe proportionately greater. There is no data extant at this time to demonstrate conclusively the actual difference in velocity of flow between these two forms of pipe, but in an endeavor to reach a fair conception of this difference it has been assumed that a variation of .001 in the coefficient of the Kutter formula would probably result in as close an approximation as circumstances would warrant. Based on this assumption, the capacity of the lock-bar pipe, 48 inches in diameter would be 8½ per cent. greater than a riveted pipe of the same diameter. Other sizes would vary proportionately.

"As a resume, therefore, it may be stated that the lock-bar pipe possesses two points of marked supremacy over riveted pipe, first, an advantage of 12½ per cent in the value of the pipe due to its increased strength, and second, 8½ per cent on account of greater capacity, a total of 21 per cent to the credit of the lock-bar pipe.

"These deductions may be open to some alterations due to conditions, cost of manufacture, size of pipe, and some other minor points, although in general they may be accepted as fair. But making due allowance for some such criticism it may be

stated broadly that *the net value of the lock-bar pipe is from 15 to 20 per cent greater than riveted pipe of the same diameter and thickness.*"

Mr. F. C. Dunlap, in 1908 Chief, Bureau of Water of Philadelphia, where 54,000 feet of 48- and 36-inch LOCK-BAR STEEL PIPE was laid in 1907-8, wrote regarding this installation:

"The carrying capacity of LOCK-BAR STEEL PIPE is probably ten to twelve per cent greater than that of the ordinary in and out or taper sheet, riveted pipe. As far as I know there have been no tests made to determine this point, but in my opinion, the continuously regular inside surface of the LOCK-BAR PIPE, with circular joints thirty feet apart, will produce no greater frictional resistance than well coated cast iron pipe with joints every twelve feet."

Mr. W. H. Sutherland, of the Montreal Water and Power Company, laid 36,000 feet of LOCK-BAR steel pipe in Montreal in 1907-1909, and had the following to say relative to the carrying capacity of the line:

"We have a line approximately 36,000 feet in length and are pumping into this at the rate of 11,800 U. S. gallons per minute by Venturi meter. At a point 12,000 feet from the pump station water is drawn at the rate of 2,333 U. S. gallons per minute, also measured by Venturi meter. Readings of pressure were taken with Bristol recording pressure gauges, and the gauges tested by means of a Crosby gauge tester before and after the 12 hours records. Elevations of gauges were well established. The average friction loss for three hours while conditions were constant in the whole line was 28.27 feet. The figure given in Coffin's tables for clean cast-iron pipes under the above conditions is 30.7 feet, and, in our experience the actual friction loss in cast-iron pipes that have been in service a few years is about 50% higher than is given in these tables. Hence we estimate that if this line were laid in cast-iron, the friction would be at least 45 feet or 59.2% more than the observed friction in our steel main. The first section of this main, 12,000 feet, was laid in 1907 and 1908, and the balance in 1909."

Mr. J. Waldo Smith, former Chief Engineer and now Consulting Engineer, Board of Water Supply for New York City,

under date of February 24, 1920, wrote as follows respecting LOCK-BAR steel pipe:

"In this vicinity there is a strong preference for lock-bar pipe for all sizes to which it is adaptable. The East Jersey Water Company, the largest user of steel pipe in the East and which has laid several hundred miles, has not, since the perfection of the lock-bar, used any other type. Its particular advantages are:

"1. Additional strength for the same thickness of pipe.

"2. Superior hydraulic qualities, due to the elimination of 75% of the circular riveted joints and one riveted longitudinal seam and the ability to produce a smoother coating.

"The amount of gain in carrying capacity is largely a matter of judgment, for so far as I know, there have been no reliable experiments of capacity of riveted and lock-bar pipe of the same age under comparable conditions.

"That the gain in capacity is considerable is unquestionable. My own judgment is that it might easily reach 15%, as the smoothness of coating in itself conduces to a higher coefficient. The little roughnesses in riveted pipe, such as are caused in the dipping and draining of the pipe by the presence of the rivets, to which the coating is apt to adhere and drip during the draining process, together with the rivets and seams, increase the friction more than is supposed.

"The lock-bar pipe was used on the Catskill work wherever it was applicable, such as some of the main delivery lines within the city. *In the light of present experience, one would hardly consider the use of riveted pipe if lock-bar could be secured.*

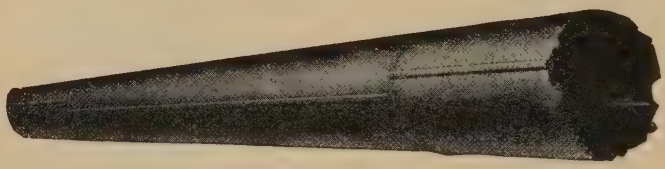
"As to the life of steel pipe, in broad terms a pipe protected with the best type of coating and well laid should last upwards of 50 years. This estimate is based on knowledge of lines built in the East, where the coating was inferior to that now available and which have been in operation over 20 years and seem to be good for an indefinite period. Also lines in California have been in operation around 40 years and where examination has been made show only a slight deterioration. The Engineers of the Board of Water Supply had confidence enough in steel pipe to lay it in the streets, believing that it would compare very favorably in its life with cast-iron pipe."

Partial List of Lock-Bar Pipe Lines

		Feet	Size
1905	Pittsburgh, Pa	2,500	30″
"	Paterson, N. J	11,000	48″ & 42″
"	Lynchburg, Va	11,500	30″
"	Wilmington, Del	20,000	48″ & 43″
1906	Honolulu, T. H	8,000	30″
"	Philadelphia, Pa	55,300	48″ & 36″
1907	Gary, Ind	4,000	36″
"	Trenton, N. J	10,000	48″
"	Montreal, P. Q	11,000	36″
"	Lockport, N. Y	68,500	30″
"	Vancouver, B. C	5,000	22″
1908	Michigan City, Ind	4,000	30″
"	Montreal, P. Q	25,000	36″
"	Springfield, Mass	63,500	54″ & 42″
1909	Brooklyn, N. Y	83,000	72″
"	Portland, Ore	9,600	48″ to 24″
1910	Brooklyn, N. Y	16,200	48″
"	Ensley, Ala	8,840	50″
"	Pittsburgh, Pa	5,000	24″
"	Cuba	1,300	36″ & 28″
"	Washington, D. C	1,220	30″
"	Seattle, Wash	4,050	32″
"	Seattle, Wash	12,300	42″ to 24″
"	Portland, Ore	128,000	52″ & 44″
"	Butte, Mont	1,200	42″
"	New York, N. Y	1,200	48″ to 30″
1911	Catskill Aqueduct, N. Y	8,510	66″
"	Lakeland, Fla	4,020	20″
"	Pennsylvania R. R	7,770	20″
"	Massena, N. Y	1,323	24″
1911	Seattle, Wash	16,945	42″ to 24″
"	Montreal, P. Q	7,300	48″ to 30″
"	Denver, Colo	1,200	60″
"	Marquette, Mich	8,000	66″
1912	Union Bay, B. C	1,320	50″
"	Rochester, N. Y	9,254	66″
"	Ottawa, Ont	2,400	42″
"	Omaha, Neb	10,550	48″
"	Akron, Ohio	55,870	36″
"	Winnipeg, Man	42,500	36″
1913	Minneapolis, Minn	39,725	54″50″&48″
"	Montclair, N. J	7,295	24″
"	Massena, N. Y	1,200	24″
"	Utica, N. Y	1,000	36″
"	Wilkes-Barre, Pa	1,335	36″
"	Schenectady, N. Y	2,420	24″
1914	Schenectady, N. Y	10,500	36″

		Feet	Size
1914	Essex Junction, Vt.	2,440	108″ & 36″
"	Rutland, Vt.	2,750	54″
"	Winnipeg, Man.	24,000	36″
"	Brooklyn, N. Y.	12,200	66″
"	Rochester, N. Y.	1,120	66″ & 48″
1915	Minneapolis, Minn.	7,355	40″ & 48″
"	Ottawa, Ont.	15,000	51″
1916	Seattle, Wash.	1,324	42″
"	Ottawa, Ont.	1,945	51″
"	Minneapolis, Minn.	7,341	40″ & 48″
"	Seattle, Wash.	1,301	42″
"	Rochester, N. Y.	50,754	37″
"	St. Louis, Mo.	26,700	36″
"	Brandon, Vt.	2,344	36″
"	Gary, Ind.	1,865	36″
1917	Eastman Kodak Co., Rochester, N. Y.	7,910	42″
"	Rochester, N. Y.	42,140	37″
"	Carnegie Natural Gas Co.	48,537	54″ to 30″
1918	Carnegie Natural Gas Co.	12,000	40″
1919	Akron, Ohio.	12,000	48″
"	Jersey City, N. J.	88,000	72″
1920	Elyria, Ohio.	24,500	36″
"	Port Henry, Vermont.	3,000	36″ & 40″
"	Passaic, N. J.	12,300	30″
"	Salt Lake City, Utah.	1,200	36″
"	Bayonne, N. J.	44,000	48″
"	Akron, Ohio.	21,250	48″
"	Detroit, Mich.	21,930	48″
1921	Detroit, Mich.	13,000	48″
"	Saginaw, Mich.	5,000	36″
"	Detroit, Mich.	6,000	48″
"	Philadelphia, Pa.	1,000	36″
"	Philadelphia, Pa.	7,000	60″
"	Philadelphia, Pa.	2,500	72″
1922	Cleveland, Ohio.	20,000	60″
"	Montreal, Canada.	11,000	48″
"	Montreal, Canada.	2,000	36″
"	Detroit, Mich.	5,000	36″
"	Bay City, Mich.	4,000	48″
1923	Cleveland, Ohio.	10,400	60″
"	B. W. S., Brooklyn, N. Y.	16,800	66″ to 72″
"	Detroit, Mich.	7,890	24″
"	B. W. S., Brooklyn, N. Y.	41,430	66″ to 72″
"	Kearny, N. J.	5,600	30″
"	Elyria, Ohio.	1,400	36″
"	Portland, Ore.	132,000	50″ & 58″
1924	Boston, Mass.	11,400	68″
"	Kearny, N. J.	5,150	30″
"	Philadelphia, Pa.	9,100	48″

		Feet	Size
1924	Cleveland, Ohio	6,500	48″
"	Boston, Mass	15,359	60″
"	Seattle, Wash	13,000	54″
"	Boston, Mass	17,600	56″
"	Seattle, Wash	15,217	24″ 30″ 36″
"	Cleveland, Ohio	1,222	42″
1925	Seattle, Wash	1,050	54″
"	Philadelphia, Pa	7,500	36″
"	New York, N. Y	14,360	72″
"	Cleveland, Ohio	11,700	48″
"	Cleveland, Ohio	15,750	36″
"	Cleveland, Ohio	1,575	48″
"	Tacoma, Wash	2,276	64″
"	Seattle, Wash	3,026	58″
"	Seattle, Wash	3,160	24″
"	Detroit, Mich	24,180	60″
"	Detroit, Mich	9,566	48″
"	Seattle, Wash	8,333	42″
"	Seattle, Wash	3,210	42″
"	Montreal, Canada	2,583	42″
"	Montreal, Canada	11,000	48″
"	Garfield, N. J	7,600	30″
"	Omaha, Nebraska	21,970	48″
"	Philadelphia, Pa	2,800	30″
1926	Garfield, N. J	7,600	30″
"	Seattle, Wash	8,330	54″
"	Portland, Ore	22,775	24″ & 40″
"	Tacoma, Wash	2,600	52″
"	Fairbanks, Alaska	34,380	46″ to 56″
"	San Diego, Calif	88,791	36″
"	New York, N. Y	1,072	36″
"	Montreal, Canada	2,583	36″
"	Garfield, N. J	5,185	30″
"	Kearny, N. J., No. 8	4,300	36″
1927	Miami, Florida	3,050	51″ 48″ 45″
"	San Francisco, Calif	55,000	54″
"	Kearny, N. J	23,677	30″ & 36″ 42″ 48″
"	Newark, N. J	610	30″
"	Minneapolis, Minn	30,000	48″
1928	Minneapolis, Minn	19,130	48″
"	New York, N. Y	9,270	48″ & 36″
"	Stevens & Wood, Penns Grove, N. J	3,257	54″
"	Kearny, N. J., No. 10-A	8,650	48″
"	Kearny, N. J., No. 10-B	1,020	42″
"	St. John, N. B., Canada	5,465	36″
1929	Wanaque Aqueduct, N. J	171,500	74″
"	Seattle, Wash	28,000	54″
"	Newark, N. J	25,400	60″
"	Minneapolis, Minn	15,500	48″
"	Pittsburgh, Pa	1,100	36″
1929	Detroit, Mich	14,700	48″ & 60″



Riveted Taper Joint

The most successful type of field seam for ordinary installations where the pipe diameter is sufficiently large for riveting and caulking on the inside. The larger end of the pipe fits over the smaller or taper end of the contiguous pipe. After riveting, the joint is caulked both inside and out. All interior seams point in the direction of the line of flow.

Some early Riveted Steel Pipe Lines manufactured by East Jersey Pipe Company for conveyance of water supply:

Year	Location	Size	Approximate Length (Feet)
1891	Newark, N. J.	36″ & 48″	142,000
1896	Newark, N. J.	48″ & 42″	125,000
1897	Paterson, N. J.	42″	40,000
1899	Seattle, Wash.	42″	32,000
1899	Newark, N. J.	51″	47,500
1902	Jersey City, N. J.	72″	93,000
1903	Newark, N. J.	60″	39,300
1903	Troy, N. Y.	33″	35,300
1903	Schenectady, N. Y.	36″	22,000
1904	Astoria, Long Island	60″	15,000
1906	Brooklyn, N. Y.	72″	42,300
1908	Philadelphia, Pa.	132″	1,590
1910	Catskill Aqueduct, N. Y.	135″, 117″ & 114″	33,000
1911	Catskill Aqueduct, N. Y.	66″	8,510
1912	Chihuahua, Mexico	102″	1,400
1913	Kansas City, Mo.	48″	1,220
1913	Croghan, N. Y.	114″	2,555
1914	Essex Junction, Ver.	108″ & 36″	2,440

Extract from *New York Daily Tribune*, Tuesday, October 13, 1903.

Newark Lends Water Supply

Sends Thirty Million Gallons Daily to Jersey City—Reservoir in Danger

Yesterday Jersey City received its water supply from Newark. The supply for Jersey City comes from the East Jersey Water Company's plant at Little Falls. The storm put out of service all but one of the pumps, and in consequence Newark was appealed to. The amount of 30,000,000 gallons was supplied yesterday, and the supply will be kept up until the plant at Little Falls is in order. Newark and the East Jersey Water Company have a contract under which Newark supplies to the company water from its excess supply at the rate of 2,000,000 gallons for one acre of land in the Pequannock watershed owned by the company. The city has already obtained from the company more than three thousand acres in exchange for its excess water.

Morris R. Sherrerd, of the Newark Water Department, after an inspection of the watershed, which he undertook Saturday night, said yesterday:

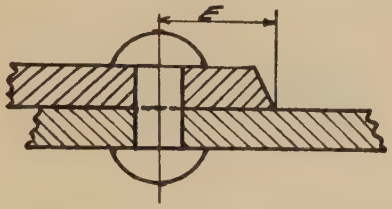
"The principal danger to the line was where the pipes cross the Pequannock River, opposite Smith's Mills, about a mile and a half below the intake. Two pipes cross the river there, one on the bed of the stream and the other, a forty-eight inch wrought-iron pipe, on a trestle over the stream. A little trout stream near the place was swollen to the dimensions of a river, and the mountain brooks, joining with it, twisted the dam out of condition, while the water carried the debris, trees and parts of buildings, choking one of the culverts.

"The rushing waters washed away two of the abutments or piers under the pipe-line trestle, leaving forty feet of the pipes unsupported. Not only did the pipe have to carry its own weight and that of the water passing through it, but great masses of masonry of the piers had clung to the pipe, increasing the weight by several tons. The pipe stood the strain well, but if it had been a cast-iron pipe it certainly would have gone. When we found the condition of the pipe, we got men to work right in the water, and shored the pipe up so that it is safe for the present, or until we can get at it to properly repair the piers.

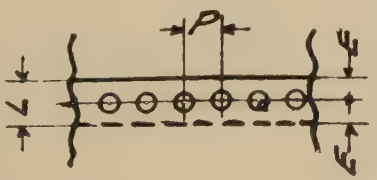
"If that pipe had gone the city would not have been able to get water from there for fully a week, owing to the railroad beds being washed out, so that it would be next to impossible to get material there. We went Saturday night to Little Falls, where we put up at the home of one of our people. By keeping on the high ground we were able to get to the place by way of Mountain View and Totowa. We were in sight of the Passaic River all the time, and noticed that it was fully two miles in width all the way. The only bridge now standing by which access can be had to Pompton Plains is the one that crosses the river at Pequannock."

See pages 168, 169 and 170.

Standard Riveting for Longitudinal Lap Seams



Thickness of Plate	Diameter of Rivet	Single Riveted Lap		
		Pitch *P*	Edge Distance *E*	Lap *L*
3/16″	1/2″	1 5/8″	15/16″	1 7/8″
1/4″	5/8″	1 7/8″	1 1/8″	2 1/4″
5/16″	3/4″	2 1/8″	1 5/16″	2 5/8″
3/8″	7/8″	2 3/8″	1 7/16″	2 7/8″
7/16″	1″	2 5/8″	1 5/8″	3 1/4″
1/2″	1″	2 1/2″	1 5/8″	3 1/4″
9/16″	1″	2 3/8″	1 5/8″	3 1/4″
5/8″	1″	2 1/4″	1 5/8″	3 1/4″
11/16″ and 3/4″	1″	2 1/4″	1 5/8″	3 1/4″
13/16″ and 7/8″	1 1/8″	3″	1 7/8″	3 3/4″

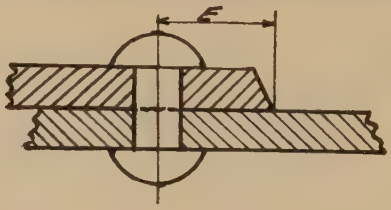


Rivet holes punched 1/16″ larger in diameter than rivet.

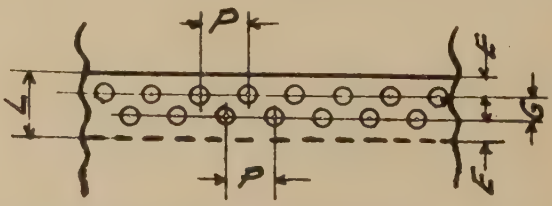
When holes are sub-punched and reamed, holes will be punched 1/16″ smaller in diameter than rivet and reamed 1/16″ larger than rivet.

All holes will be punched full size and not reamed before fitting up unless by special agreement.

Standard Riveting for Longitudinal Lap Seams



Thickness of Plate	Diameter of Rivet	Double Riveted Lap			
		Pitch *P*	Gauge *G*	Edge Distance *E*	Lap *L*
3/16″	1/2″	2 1/2″	1 5/8″	15/16″	3 1/2″
1/4″	5/8″	2 5/8″	1 3/4″	1 1/8″	4″
5/16″	3/4″	2 7/8″	1 7/8″	1 5/16″	4 1/2″
3/8″	7/8″	3 1/4″	2″	1 7/16″	4 7/8″
7/16″	1″	3 1/2″	2 1/8″	1 5/8″	5 3/8″
1/2″	1″	3 3/8″	2 1/4″	1 5/8″	5 1/2″
9/16″	1″	3 1/4″	2 1/4″	1 5/8″	5 1/2″
5/8″	1″	3 1/8″	2 1/4″	1 5/8″	5 1/2″
11/16″ and 3/4″	1″	3″	2 1/4″	1 5/8″	5 1/2″
13/16″ and 7/8″	1 1/8″	3 1/2″	2 1/4″	1 7/8″	6″

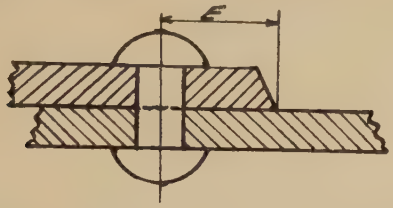


Rivet holes punched 1/16″ larger in diameter than rivet.

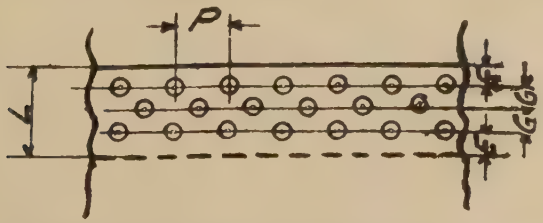
When holes are sub-punched and reamed, holes will be punched 1/16″ smaller in diameter than rivet and reamed 1/16″ larger than rivet.

All holes will be punched full size and not reamed before fitting up unless by special agreement.

Standard Riveting for Longitudinal Lap Seams



Thickness of Plate	Diameter of Rivet	Triple Riveted Lap			
		Pitch *P*	Gauge *G*	Edge Distance *E*	Lap *L*
3/16″	1/2″	2 3/4″	1 7/8″	15/16″	5 5/8″
1/4″	5/8″	3 1/4″	2″	1 1/8″	6 1/4″
5/16″	3/4″	3 3/4″	2 1/8″	1 5/16″	6 7/8″
3/8″	7/8″	4 3/8″	2 1/4″	1 7/16″	7 3/8″
7/16″	1″	4 1/2″	2 3/8″	1 5/8″	8″
1/2″	1″	4 1/2″	2 1/2″	1 5/8″	8 1/4″
9/16″	1″	4 3/8″	2 1/2″	1 5/8″	8 1/4″
5/8″	1″	4 1/4″	2 1/2″	1 5/8″	8 1/4″
11/16″ and 3/4″	1″	4″	2 1/2″	1 5/8″	8 1/4″
13/16″ and 7/8″	1 1/8″	4 1/2″	2 1/2″	1 7/8″	8 3/4″



Rivet holes punched 1/16″ larger in diameter than rivet.

When holes are sub-punched and reamed, holes will be punched 1/16″ smaller in diameter than rivet and reamed 1/16″ larger than rivet.

All holes will be punched full size and not reamed before fitting up unless by special agreement.

Standard Number of Rivets in Single Riveted Circular Seams

Thickness of Plate	3/16″	1/4″	5/16″	3/8″	7/16″	1/2″
Dia. of Rivets	1/2″	5/8″	3/4″	7/8″	1″	1″
Dia. of Pipe	Number of Rivets					
18″	36	28	28	24	20	24
19″	36	32	28	24	24	24
20″	40	32	28	28	24	24
21″	40	36	32	28	24	28
22″	44	36	32	28	28	28
23″	44	40	36	32	28	28
24″	48	40	36	32	28	32
25″	48	40	36	32	28	32
26″	52	44	40	36	32	32
27″	52	48	40	36	32	36
28″	56	48	40	36	32	36
29″	56	48	44	40	36	36
30″	60	52	44	40	36	40
31″	60	52	48	40	36	40
32″	60	52	48	44	40	40
33″	64	56	48	44	40	40
34″	64	56	52	44	40	44
35″	68	60	52	48	44	44
36″	68	60	52	48	44	44
37″	72	64	56	48	44	48
38″	72	64	56	52	44	48
39″	76	64	60	52	48	48
40″	76	68	60	52	48	52
41″	80	68	60	56	48	52
42″	80	72	64	56	52	52
43″	84	72	64	56	52	56
44″	84	76	68	60	52	56
45″	88	76	68	60	56	56
46″	88	80	68	60	56	60
47″	92	80	72	64	56	60
48″	92	80	72	64	60	60
49″	96	84	72	64	60	64
50″	96	84	76	68	60	64
51″	100	88	76	68	60	64
52″	100	88	80	68	64	68
53″	104	92	80	72	64	68
54″	104	92	80	72	64	68
55″	108	92	84	72	68	72
56″	108	96	84	76	68	72
57″	112	96	84	76	68	72
58″	112	100	88	76	72	76
59″	116	100	88	80	72	76
60″	116	100	88	80	72	76
61″	120	104	92	80	76	80
62″	120	104	92	84	76	80
63″	124	108	96	84	76	80
64″	124	108	96	84	76	84
65″	128	108	96	88	80	84
66″	128	112	100	88	80	84
67″	132	112	100	88	80	84
68″	132	116	104	92	84	88
69″	136	116	104	92	84	88
70″	136	120	104	96	84	88
71″	140	120	108	96	88	92
72″ and upwards	140	120	108	96	88	92

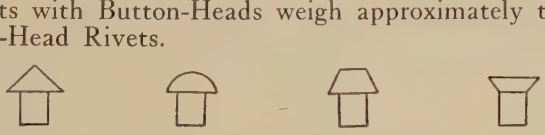
Cone-Head Boiler Rivets of Scant Diameter

(Estimated weights per hundred rivets)

Length inches	½	9/16	5/8	11/16	¾	13/16	7/8	1	1⅛*	1¼*
¾	8.75	13.7	16.20	.....	.....	.....	.....	.....	.....	.....
⅞	9.35	14.4	17.22	.....	.....	.....	.....	.....	.....	.....
1	10.00	15.2	18.25	21.70	26.55	37.0	46	60	.....	.....
1⅛	10.70	16.0	19.28	23.10	28.00	38.6	48	63	95	.....
1¼	11.40	16.8	20.31	24.50	29.45	40.2	50	65	98	133
1⅜	12.10	17.6	21.34	25.90	30.90	41.9	52	67	101	137
1½	12.80	18.4	22.37	27.30	32.35	43.5	54	69	104	141
1⅝	13.50	19.2	23.40	28.70	33.80	45.2	56	71	107	145
1¾	14.20	20.0	24.43	30.10	35.25	.....	.....	.....	.....	.....
1⅞	14.90	20.8	25.46	31.50	36.70	.....	.....	.....	.....	.....
2	15.60	21.6	26.49	32.90	38.15	47.	58	74	110	149
2⅛	16.30	22.4	27.52	34.30	39.60	48.7	60	77	114	153
2¼	17.00	23.2	28.55	35.70	41.05	50.3	62	80	118	157
2⅜	17.70	24.0	29.58	37.10	42.50	51.9	64	83	121	161
2½	18.40	24.8	30.61	38.50	43.95	53.5	66	86	124	165
2⅝	19.10	25.6	31.64	39.90	45.40	55.1	68	89	127	169
2¾	19.80	26.4	32.67	41.30	46.85	56.8	70	92	130	173
2⅞	20.50	27.2	33.70	42.70	48.30	58.4	72	95	133	177
3	21.20	28.0	34.73	44.10	49.75	60.	74	98	137	181
3¼	22.60	29.7	36.79	46.90	52.65	63.3	78	103	144	189
3½	24.00	31.5	38.85	49.70	55.55	66.5	82	108	151	197
3¾	25.40	33.3	40.91	52.50	58.45	69.8	86	113	158	205
4	26.80	35.2	42.97	55.30	61.35	73.	90	118	165	213
4¼	28.20	36.9	45.00	58.10	64.25	76.3	94	124	172	221
4½	29.60	38.6	47.09	60.90	67.15	79.5	98	130	179	229
4¾	31.00	40.3	49.15	63.70	70.05	82.8	102	136	186	237
5	32.40	42.0	51.21	66.50	72.95	86.	106.	142	193	245
5¼	33.80	43.7	53.27	69.20	75.85	89.3	110	148	200	254
5½	35.20	45.4	55.33	72.00	78.75	92.5	114	154	206	263
5¾	36.60	47.1	57.39	74.80	81.65	95.7	118	160	212	272
6	38.00	48.8	59.45	77.60	84.55	99.	122	166	218	281
6½	40.80	52.0	63.57	83.30	90.35	105.5	130	177	231	297
7	43.60	55.2	67.69	88.90	96.15	112.	138	188	245	314
Heads....	5.50	8.40	11.50	13.20	18.00	23.0	29.0	38.0	56.0	77.5

*These two sizes are calculated for exact diameter.

Rivets with Button-Heads weigh approximately the same as Cone-Head Rivets.



Steeple. Round. Cone. Countersunk.

The measure of Countersunk Head Rivets is over all. All other styles are measured from under the head. Boiler Rivets less than one inch long are one-half cent per pound extra. Tank Rivets 7/16 inch in diameter and less are sold at a list price and subject to discount.

Shearing and Bearing Value of Rivets

(Steel Institute Standard)

Unless special values are called for by city building ordinances, it is customary to use a
Shearing value of 13,500 pounds per square inch for Shop Rivets,
Shearing value of 10,000 pounds per square inch for Field Rivets,
Bearing value of 24,000 pounds for Shop and 16,000 pounds for Field Rivets,

Diameter of Rivet, Inches	Area, Square Inches	Single Shear at 7,500 Pounds	Bearing Value in Pounds for Different Thickness of Plate in Inches at 15,000 Lbs. per Sq. In.												
			1/4	5/16	3/8	7/16	1/2	9/16	5/8	11/16	3/4	13/16	7/8	15/16	1
3/8	.1104	830	1410	1760	2110	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
1/2	.1963	1470	1880	2340	2810	3280	3750	.....	.....	.....	.....	.....	.....	.....	.....
5/8	.3068	2300	2340	2930	3520	4100	4690	5280	5860	.....	.....	.....	.....	.....	.....
3/4	.4418	3310	2810	3520	4220	4920	5630	6330	7030	7720	8440	.....	.....	.....	.....
7/8	.6013	4510	3280	4100	4920	5740	6560	7380	8200	9030	9850	10670	11480	12300	.....
1	.7854	5890	3750	4690	5620	6560	7500	8440	9380	10310	11250	12190	13130	14060	15000

Diameter of Rivet, Inches	Area, Square Inches	Single Shear at 9,000 Pounds	Bearing Value in Pounds for Different Thickness of Plate in Inches at 18,000 Lbs. per Sq. In.												
			1/4	5/16	3/8	7/16	1/2	9/16	5/8	11/16	3/4	13/16	7/8	15/16	1
3/8	.1104	990	1680	2110	2530	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
1/2	.1963	1770	2250	2820	3370	3940	4500	.....	.....	.....	.....	.....	.....	.....	.....
5/8	.3068	2760	2790	3480	4180	4870	5580	6330	7030	.....	.....	.....	.....	.....	.....
3/4	.4418	3970	3370	4210	5050	5910	6750	7590	8440	9280	10130	.....	.....	.....	.....
7/8	.6013	5410	3940	4920	5910	6880	7870	8860	9840	10830	11810	12800	13780	14770	.....
1	.7854	7060	4500	5620	6750	7870	9000	10120	11250	12370	13500	14630	15750	16880	18000

Shearing and Bearing Value of Rivets—Continued

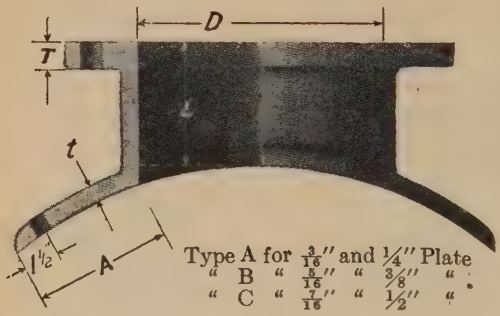
Diameter of Rivet, Inches	Area, Square Inches	Single Shear at 10,000 Pounds	Bearing Value in Pounds for Different Thickness of Plate in Inches at 20,000 Lbs. per Sq. In.												
			1/4	5/16	3/8	7/16	1/2	9/16	5/8	11/16	3/4	13/16	7/8	15/16	1
3/8	.1104	1100	1880	2340	2810	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
1/2	.1963	1960	2500	3130	3750	4380	5000	.....	.....	.....	.....	.....	.....	.....	.....
5/8	.3068	3070	3130	3910	4690	5470	6250	7030	7810	.....	.....	.....	.....	.....	.....
3/4	.4418	4420	3750	4690	5630	6560	7500	8440	9380	10310	11250	.....	.....	.....	.....
7/8	.6013	6010	4380	5470	6570	7660	8750	9840	10940	12030	13130	14220	15310	16410	.....
1	.7854	7850	5000	6250	7500	8750	10000	11250	12500	13750	15000	16250	17500	18750	20000

Diameter of Rivet, Inches	Area, Square Inches	Single Shear at 12,000 Pounds	Bearing Value in Pounds for Different Thickness of Plate in Inches at 24,000 Lbs. per Sq. In.												
			1/4	5/16	3/8	7/16	1/2	9/16	5/8	11/16	3/4	13/16	7/8	15/16	1
3/8	.1104	1320	2250	2810	3380	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
1/2	.1963	2360	3000	3750	4500	5250	6000	.....	.....	.....	.....	.....	.....	.....	.....
5/8	.3068	3680	3750	4690	5630	6560	7500	8440	9380	.....	.....	.....	.....	.....	.....
3/4	.4418	5300	4500	5630	6750	7880	9000	10130	11250	12380	13500	.....	.....	.....	.....
7/8	.6013	7220	5250	6560	7880	9190	10500	11810	13130	14440	15750	17060	18380	.....	.....
1	.7854	9430	6000	7500	9000	10500	12000	13500	15000	16500	18000	19500	21000	22500	24000

Bearing values given above or to the right of the upper zigzag lines are greater than double shear.

Bearing values given between upper and lower zigzag lines are less than double shear and greater than single shear.

Bearing values given below or to the left of the lower zigzag lines are less than single shear.

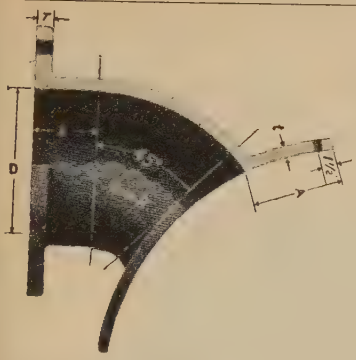


Type A for $\frac{3}{16}$" and ¼" Plate
" B " $\frac{5}{16}$" " ⅜" "
" C " $\frac{7}{16}$" " ½" "

Straight Saddles 125 Lbs. Pressure

Manufactured of cast steel and amply heavy to stand up under duty without fear of breakage. Provided with flange end and made in the several sizes listed.

Diameter D	Length L	Thickness t	Thickness T	A	Saddle Flange			Straight Flange			
					Type	No. of Holes	Dia. of Holes	O. D.	B. C.	No. of Holes	Size of Holes
4"	4"	⅝"	⅞"	5"	A B C	20 16 12	11/16" 13/16" 1 1/16"	9"	7½"	8	¾"
6"	4⅝"	⅝"	1"	5½"	A B C	24 20 16	11/16" 13/16" 1 1/16"	11"	9½"	8	⅞"
8"	4¾"	¾"	1"	5¾"	A B C	28 24 16	11/16" 13/16" 1 1/16"	13½"	11¾"	8	⅞"
10"	4¾"	¾"	1"	6"	A B C	28 24 16	11/16" 13/16" 1 1/16"	16"	14¼"	12	1"
12"	5¾"	¾"	1⅛"	6½"	A B C	32 28 20	11/16" 13/16" 1 1/16"	19"	17"	12	1"
16"	5⅞"	⅞"	1⅛"	6¾"	A B C	36 32 24	11/16" 13/16" 1 1/16"	23½"	21¼"	16	1⅛"
20"	6⅞"	⅞"	1⅛"	6¾"	A B C	48 44 36	11/16" 13/16" 1 1/16"	27½"	25"	20	1¼"
24"	6⅞"	⅞"	1¼"	6¾"	A B C	48 44 36	11/16" 13/16" 1 1/16"	32"	29½"	20	1⅜"
30"	8"	1"	1¼"	7"	A B C	56 32 44	11/16" 13/16" 1 1/16"	38¾"	36"	28	1⅜"
36"	10"	1⅛"	1½"	7¼"	A B C	64 60 52	11/16" 13/16" 1 1/16"	46"	42¾"	32	1⅝"
48"	10"	1⅛"	1½"	7¾"	A B C	76 72 64	11/16" 13/16" 1 1/16"	59½"	56"	44	1⅝"

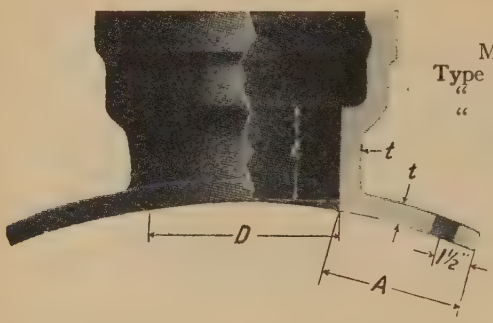


Type A for 3/16" and 1/4" Plate
" B " 5/16" " 3/8" "
" C " 7/16" " 1/2" "

Standard Blow Off Connections

Manufactured of cast steel, with ample metal at all points. Flange joint connection. Built in the several sizes listed.

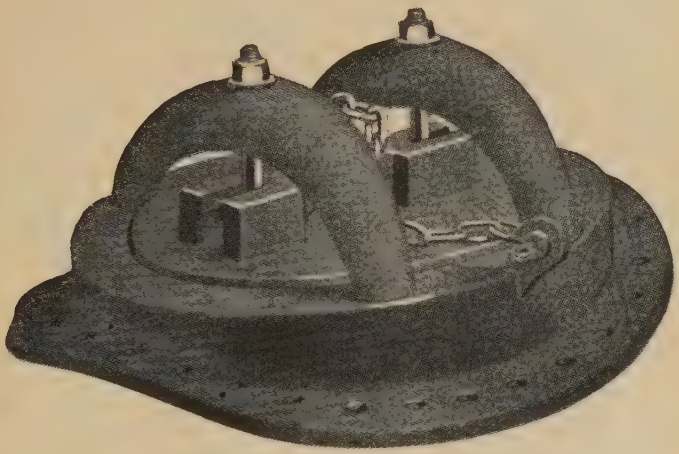
Diameter *D*	Length *L*	Thickness *t*	Thickness *T*	*A*	Radius *R*	Saddle Flange			Straight Flange			
						Type	No. of Holes	Dia. of Holes	O. D.	B. C.	No. of Holes	Size of Holes
4"	3"	5/8"	7/8"	5"	6"	A B C	20 16 12	11/16" 13/16" 1 1/16"	9"	7 1/2"	8	3/4"
6"	4"	5/8"	1"	5 1/2"	7"	A B C	24 20 16	11/16" 13/16" 1 1/16"	11"	9 1/2"	8	7/8"
8"	4"	3/4"	1"	5 3/4"	8 1/2"	A B C	28 24 16	11/16" 13/16" 1 1/16"	13 1/2"	11 3/4"	8	7/8"
10"	4"	3/4"	1"	6"	8 11/16"	A B C	28 24 16	11/16" 13/16" 1 1/16"	16"	14 1/4"	12	1"
12"	5"	3/4"	1 1/8"	6 1/2"	9 1/4"	A B C	32 28 20	11/16" 13/16" 1 1/16"	19"	17"	12	1"
16"	5"	7/8"	1 1/8"	6 3/4"	11"	A B C	36 32 24	11/16" 13/16" 1 1/16"	23 1/2"	21 1/4"	16	1 1/8"
20"	5"	7/8"	1 1/8"	6 3/4"	13 1/2"	A B C	48 44 36	11/16" 13/16" 1 1/16"	27 1/2"	25"	20	1 1/4"
24"	5"	7/8"	1 1/4"	6 3/4"	16"	A B C	48 44 36	11/16" 13/16" 1 1/16"	32"	29 1/2"	20	1 3/8"
30"	5"	1"	1 1/4"	7"	19"	A B C	56 32 44	11/16" 13/16" 1 1/16"	38 3/4"	36"	28	1 3/8"
36"	6"	1 1/8"	1 1/2"	7 1/4"	22"	A B C	64 60 52	11/16" 13/16" 1 1/16"	46"	42 3/4"	32	1 5/8"
48"	7"	1 1/8"	1 1/2"	7 3/4"	28"	A B C	76 72 64	11/16" 13/16" 1 1/16"	59 1/2"	56"	44	1 5/8"



Made in three Types
Type A for 3/16" and 1/4" Plate
" B " 5/16" " 3/8" "
" C " 7/16" " 1/2" "

Standard Socket Saddles

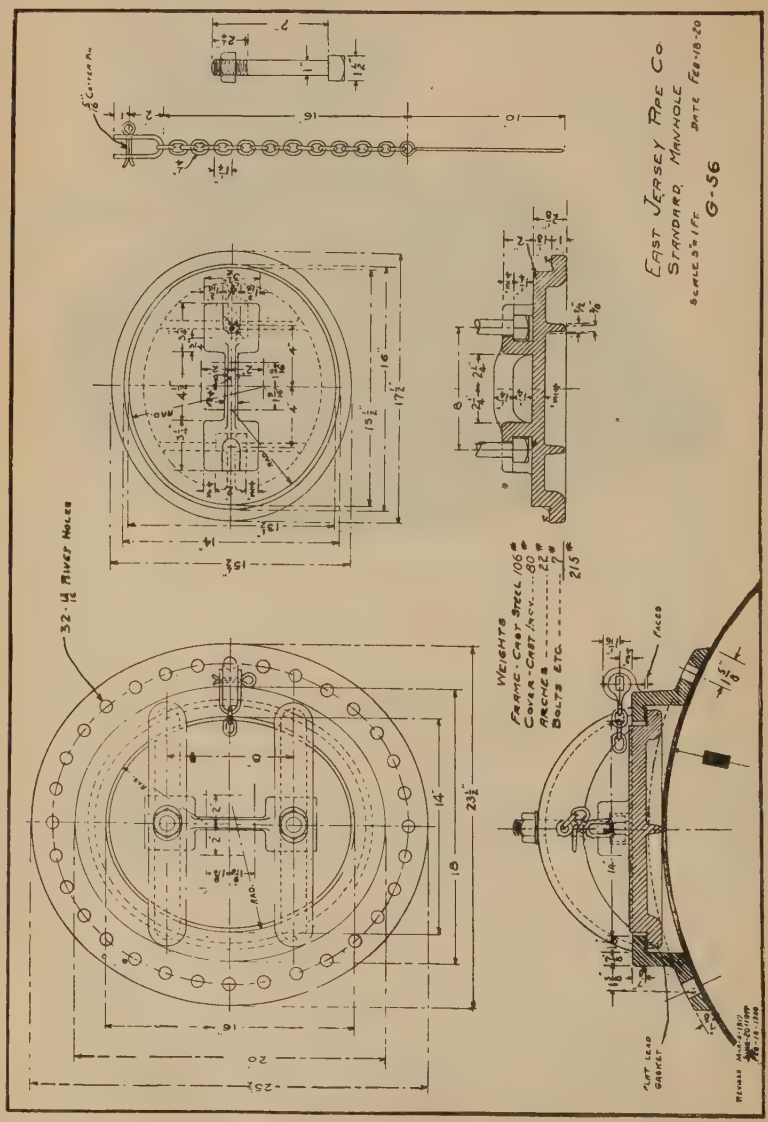
Diameter *D*	Length *L*	Thickness *t*	*A*	Saddle Flange		
				Type	Number of Holes	Diameter of Holes
6"	4 5/8"	5/8"	5 1/2"	A B C	24 20 16	11/16" 13/16" 1 1/16"
8"	4 3/4"	3/4"	5 3/4"	A B C	28 24 16	11/16" 13/16" 1 1/16"
10"	4 3/4"	3/4"	6"	A B C	28 24 16	11/16" 13/16" 1 1/16"
12"	5 3/4"	3/4"	6 1/2"	A B C	32 28 20	11/16" 13/16" 1 1/16"
16"	5 7/8"	7/8"	6 3/4"	A B C	36 32 24	11/16" 13/16" 1 1/16"
20"	6 7/8"	7/8"	6 3/4"	A B C	48 44 36	11/16" 13/16" 1 1/16"
24"	6 7/8"	7/8"	6 3/4"	A B C	48 44 36	11/16" 13/16" 1 1/16"
30"	8"	1"	7"	A B C	36 52 44	11/16" 13/16" 1 1/16"
36"	10"	1 1/8"	7 1/4"	A B C	64 60 52	11/16" 13/16" 1 1/16"
48"	10"	1 1/8"	7 3/4"	A B C	76 72 64	11/16" 13/16" 1 1/16"

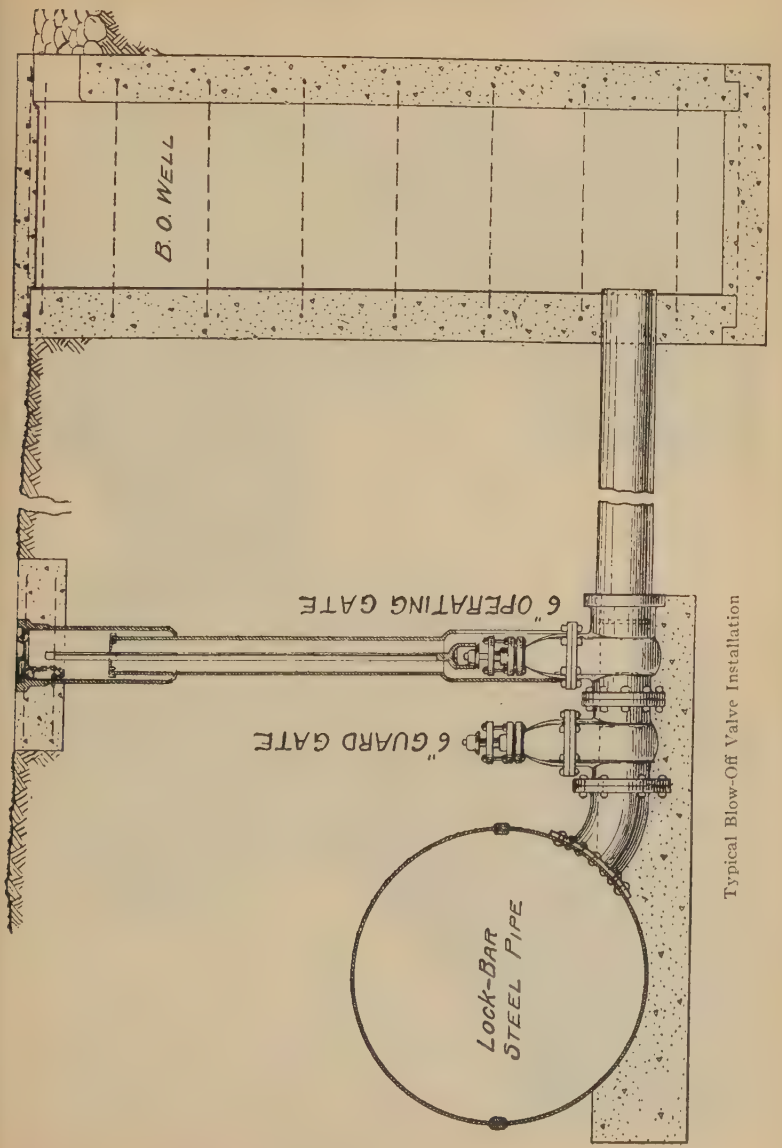


(Patented)

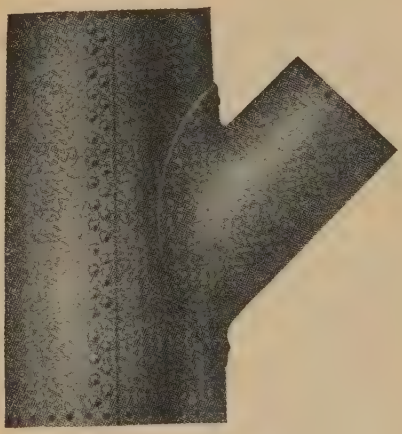
Standard Manholes

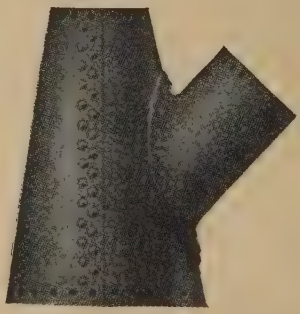
Conforming to all the requirements of safety and convenience. Manufactured of cast steel with cast iron cover and pressed steel arches. It is provided with a strong anchor chain. The Manhole opening is 14″ x 16″ oval. Standard for all thicknesses: 32 13/16″ holes for ¾″ rivets.

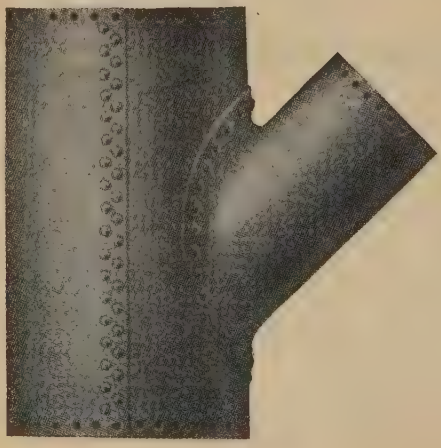

EAST JERSEY PIPE CO
STANDARD MANHOLE
G-56
SCALE 3"=1'-0"
DATE FEB-18-20
32-1¼ RIVET HOLES
WEIGHTS
FRAME-CHAIR 106#
COVER-CHAIR 80
ANGLE 22#
BOLTS ETC. 7#
215#
FACED
FLAT LEAD GASKET



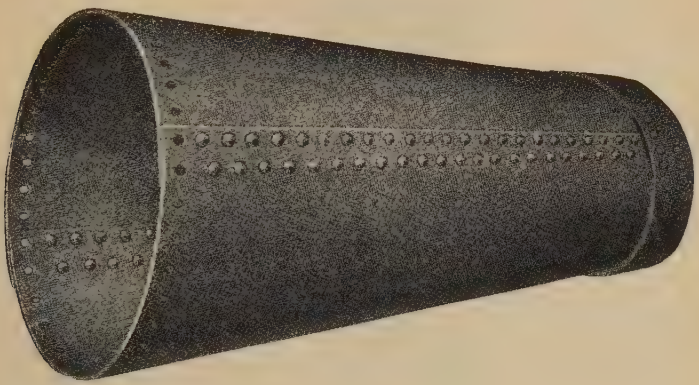
Typical Blow-Off Valve Installation

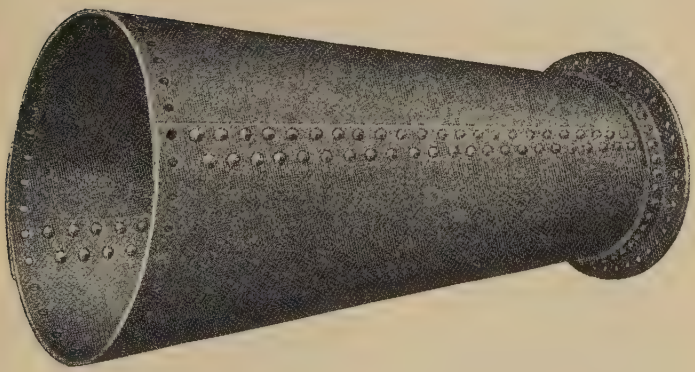






TYPES OF RIVETED
SPECIALS



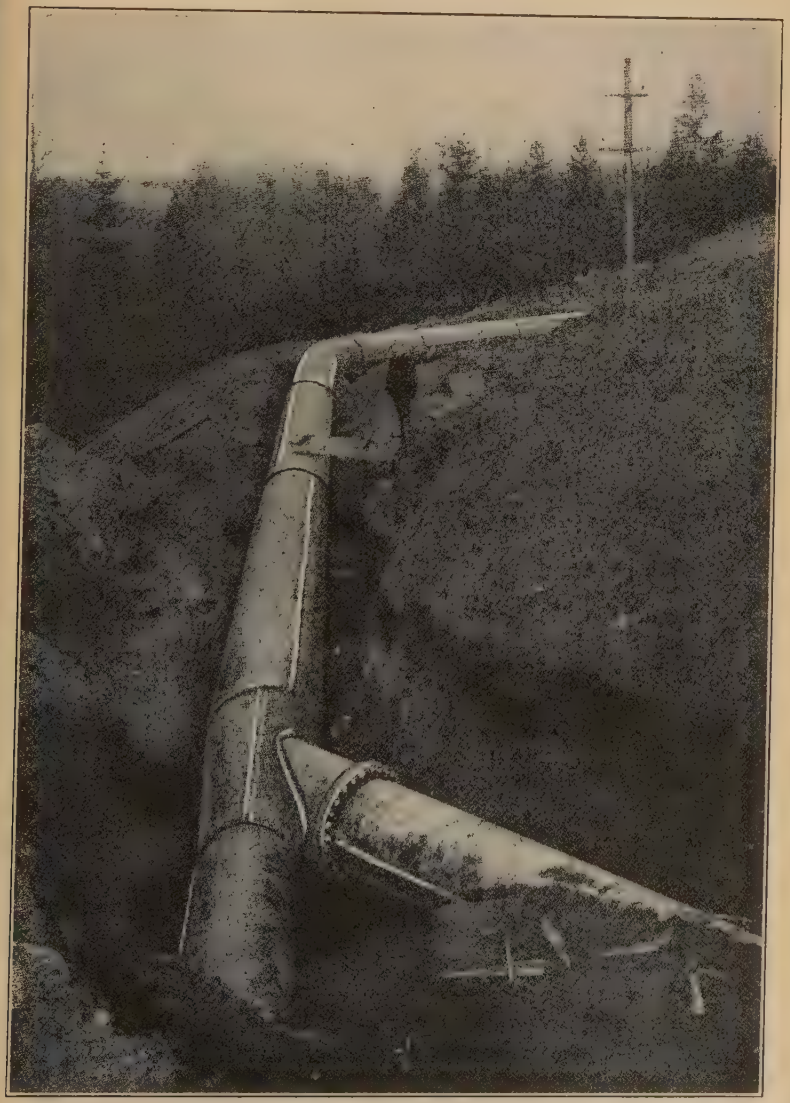


Reducers

Riveted Steel Plate Reducers are made up to meet all conditions.

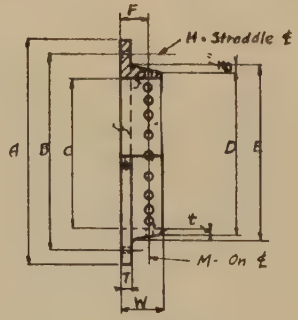
Y's and Tees

Specials are manufactured to meet all conditions. They are fabricated of steel plate and furnished with either riveted or flanged connections.

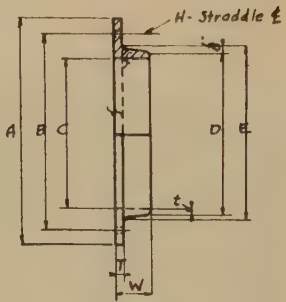


A Lock-Bar Pipe Line Showing Branch and Curve

Rolled Steel Flange
(Standard)



TYPE - X
RIVETED TO PIPE

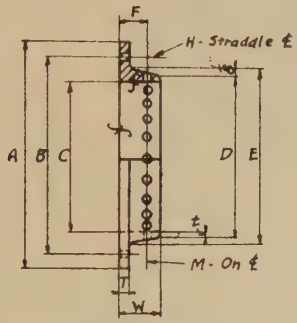


TYPE - Y
WELDED TO PIPE

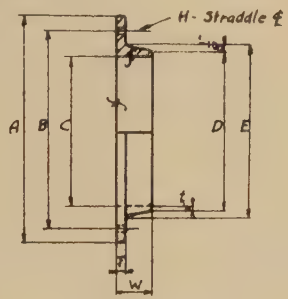
DIMENSIONS IN INCHES

MARK NO.	SIZE NOMINAL	A	B	C	D	E	F TYPE X ONLY	T	t	W TYPE X	W TYPE Y	H-HOLES	M-HOLES TYPE X ONLY
A	20 x 3/16	27 1/2	25	20 1/2	21 3/4	22	3 5/8	1 1/16	5/8	5 1/2	2	20-1 1/4	40-9 11/16
B	20 x 1/4	27 1/2	25	20 3/8	21 7/8	22 1/8	3 5/8	1 1/16	5/8	5 1/2	2	20-1 1/4	32-11/16
C	20 x 5/16	27 1/2	25	20 3/4	22	22 1/4	3 5/8	1 1/16	5/8	5 1/2	2	20-1 1/4	28-13/16
D	20 x 3/8	27 1/2	25	20 7/8	22 1/8	22 3/8	3 5/8	1 1/16	5/8	5 1/2	2	20-1 1/4	28-15/16
E	20 x 7/16	27 1/2	25	21	22 1/4	22 1/2	3 5/8	1 1/16	5/8	5 1/2	2	20-1 1/4	24-1 1/16
F	20 x 1/2	27 1/2	25	21 1/8	22 3/8	22 3/8	3 5/8	1 1/16	5/8	5 1/2	2	20-1 1/4	24-1 3/16
G	24 x 3/16	32	29 1/2	24 1/2	26	26 1/4	3 3/4	1 1/8	3/4	5 5/8	2 1/8	20-1 3/8	48-9/16
H	24 x 1/4	32	29 1/2	24 5/8	26 1/8	26 3/8	3 3/4	1 1/8	3/4	5 5/8	2 1/8	20-1 3/8	40-11/16
I	24 x 5/16	32	29 1/2	24 3/4	26 1/4	26 1/2	3 3/4	1 1/8	3/4	5 5/8	2 1/8	20-1 3/8	36-13/16
J	24 x 3/8	32	29 1/2	24 7/8	26 3/8	26 5/8	3 3/4	1 1/8	3/4	5 5/8	2 1/8	20-1 3/8	32-15/16
K	24 x 7/16	32	29 1/2	25	26 1/2	26 3/4	3 3/4	1 1/8	3/4	5 5/8	2 1/8	20-1 3/8	28-1 1/16
L	24 x 1/2	32	29 1/2	25 1/8	26 5/8	26 7/8	3 3/4	1 1/8	3/4	5 5/8	2 1/8	20-1 3/8	32-1 3/16
M	30 x 1/4	38 3/4	36	30 5/8	32 1/8	32 3/8	3 3/4	1 1/16	3/4	5 5/8	2 1/8	28-1/2	52-11/16
N	30 x 5/16	38 3/4	36	30 3/4	32 1/4	32 1/2	3 3/4	1 1/16	3/4	5 5/8	2 1/8	28-1/2	44-13/16
O	30 x 3/8	38 3/4	36	30 7/8	32 3/8	32 5/8	3 3/4	1 1/16	3/4	5 5/8	2 1/8	28-1/2	40-15/16
P	30 x 7/16	38 3/4	36	31	32 1/2	32 3/4	3 3/4	1 1/16	3/4	5 5/8	2 1/8	28-1/2	36-1 1/16
Q	30 x 1/2	38 3/4	36	31 1/8	32 5/8	32 7/8	3 3/4	1 1/16	3/4	5 5/8	2 1/8	28-1/2	40-1 3/16
R	36 x 1/4	46	42 3/4	36 5/8	38 3/8	38 5/8	3 7/8	1 1/4	7/8	5 3/4	2 1/4	32-1 5/8	60-1/16
S	36 x 5/16	46	42 3/4	36 3/4	38 1/2	38 3/4	3 7/8	1 1/4	7/8	5 3/4	2 1/4	32-1 5/8	52-13/16
T	36 x 3/8	46	42 3/4	36 7/8	38 5/8	38 7/8	3 7/8	1 1/4	7/8	5 3/4	2 1/4	32-1 5/8	48-15/16
U	36 x 7/16	46	42 3/4	37	38 3/4	39	3 7/8	1 1/4	7/8	5 3/4	2 1/4	32-1 5/8	44-1 1/16
V	36 x 1/2	46	42 3/4	37 1/8	38 7/8	39 1/8	3 7/8	1 1/4	7/8	5 3/4	2 1/4	32-1 5/8	44-1 3/16
W	42 x 1/4	53	49 1/2	42 5/8	44 3/8	44 5/8	4	1 5/16	7/8	5 7/8	2 5/16	36-1 3/4	72-11/16

Rolled Steel Flange
(Standard)



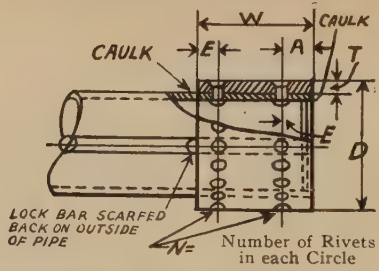
TYPE - X
RIVETED TO PIPE



TYPE - Y
WELDED TO PIPE

DIMENSIONS IN INCHES

MARK NO.	SIZE NOMINAL	A	B	C	D	E	F TYPE X ONLY	T	t	W TYPE X	W TYPE Y	H-HOLES	M-HOLES TYPE-X ONLY
AA	42 x 5/16	53	49 1/2	42 3/4	44 1/2	44 3/4	4	1 5/16	7/8	5 7/8	2 5/16	36 - 1 3/4	64 - 1 3/16
BB	42 x 3/8	53	49 1/2	42 7/8	44 5/8	44 7/8	4	1 5/16	7/8	5 7/8	2 5/16	36 - 1 3/4	56 - 1 5/16
CC	42 x 7/16	53	49 1/2	43	44 3/4	45	4	1 5/16	7/8	5 7/8	2 5/16	36 - 1 3/4	52 - 1 1/16
DD	42 x 1/2	53	49 1/2	43 1/8	44 7/8	45 1/8	4	1 5/16	7/8	5 7/8	2 5/16	36 - 1 3/4	52 - 1 3/16
EE	48 x 1/4	59 1/2	56	48 5/8	50 3/8	50 5/8	4	1 3/8	7/8	5 7/8	2 3/8	44 - 1 3/4	80 - 1 1/16
FF	48 x 5/16	59 1/2	56	48 3/4	50 1/2	50 3/4	4	1 3/8	7/8	5 7/8	2 3/8	44 - 1 3/4	72 - 1 3/16
GG	48 x 3/8	59 1/2	56	48 7/8	50 5/8	50 7/8	4	1 3/8	7/8	5 7/8	2 3/8	44 - 1 3/4	64 - 1 5/16
HH	48 x 7/16	59 1/2	56	49	50 3/4	51	4	1 3/8	7/8	5 7/8	2 3/8	44 - 1 3/4	60 - 1 1/16
II	48 x 1/2	59 1/2	56	49 1/8	50 7/8	51 1/8	4	1 3/8	7/8	5 7/8	2 3/8	44 - 1 3/4	60 - 1 3/16
JJ	54 x 5/16	66 1/4	62 3/4	54 3/4	56 1/2	56 3/4	4 1/8	1 1/2	7/8	6	2 1/2	44 - 1 7/8	80 - 1 3/16
KK	54 x 3/8	66 1/4	62 3/4	54 7/8	56 5/8	56 7/8	4 1/8	1 1/2	7/8	6	2 1/2	44 - 1 7/8	72 - 1 5/16
LL	54 x 7/16	66 1/4	62 3/4	55	56 3/4	57	4 1/8	1 1/2	7/8	6	2 1/2	44 - 1 7/8	64 - 1 1/16
MM	54 x 1/2	66 1/4	62 3/4	55 1/8	56 7/8	57 1/8	4 1/8	1 1/2	7/8	6	2 1/2	44 - 1 7/8	68 - 1 3/16
NN	60 x 5/16	73	69 1/4	60 3/4	62 5/8	62 7/8	4 3/8	1 3/4	1 5/16	6 1/4	2 3/4	52 - 1 7/8	88 - 1 3/16
OO	60 x 3/8	73	69 1/4	60 7/8	62 3/4	63	4 3/8	1 3/4	1 5/16	6 1/4	2 3/4	52 - 1 7/8	80 - 1 5/16
PP	60 x 7/16	73	69 1/4	61	62 7/8	63 1/8	4 3/8	1 3/4	1 5/16	6 1/4	2 3/4	52 - 1 7/8	72 - 1 1/16
QQ	60 x 1/2	73	69 1/4	61 1/8	63	63 1/4	4 3/8	1 3/4	1 5/16	6 1/4	2 3/4	52 - 1 7/8	76 - 1 3/16
RR	66 x 3/8	80	76	66 7/8	68 3/4	69	4 3/8	1 3/4	1 5/16	6 1/4	2 3/4	52 - 2	88 - 1 5/16
SS	66 x 7/16	80	76	67	68 7/8	69 1/8	4 3/8	1 3/4	1 5/16	6 1/4	2 3/4	52 - 2	80 - 1 1/16
TT	66 x 1/2	80	76	67 1/8	69	69 1/4	4 3/8	1 3/4	1 5/16	6 1/4	2 3/4	52 - 2	84 - 1 3/16
UU	72 x 3/8	86 1/2	82 1/2	72 7/8	74 3/4	75	4 5/8	2	1 5/16	6 1/2	3	60 - 2	96 - 1 5/16
VV	72 x 7/16	86 1/2	82 1/2	73	74 7/8	75 1/8	4 5/8	2	1 5/16	6 1/2	3	60 - 2	88 - 1 1/16
WW	72 x 1/2	86 1/2	82 1/2	73 1/8	75	75 1/4	4 5/8	2	1 5/16	6 1/2	3	60 - 2	92 - 1 3/16



STANDARD BEAD BANDS

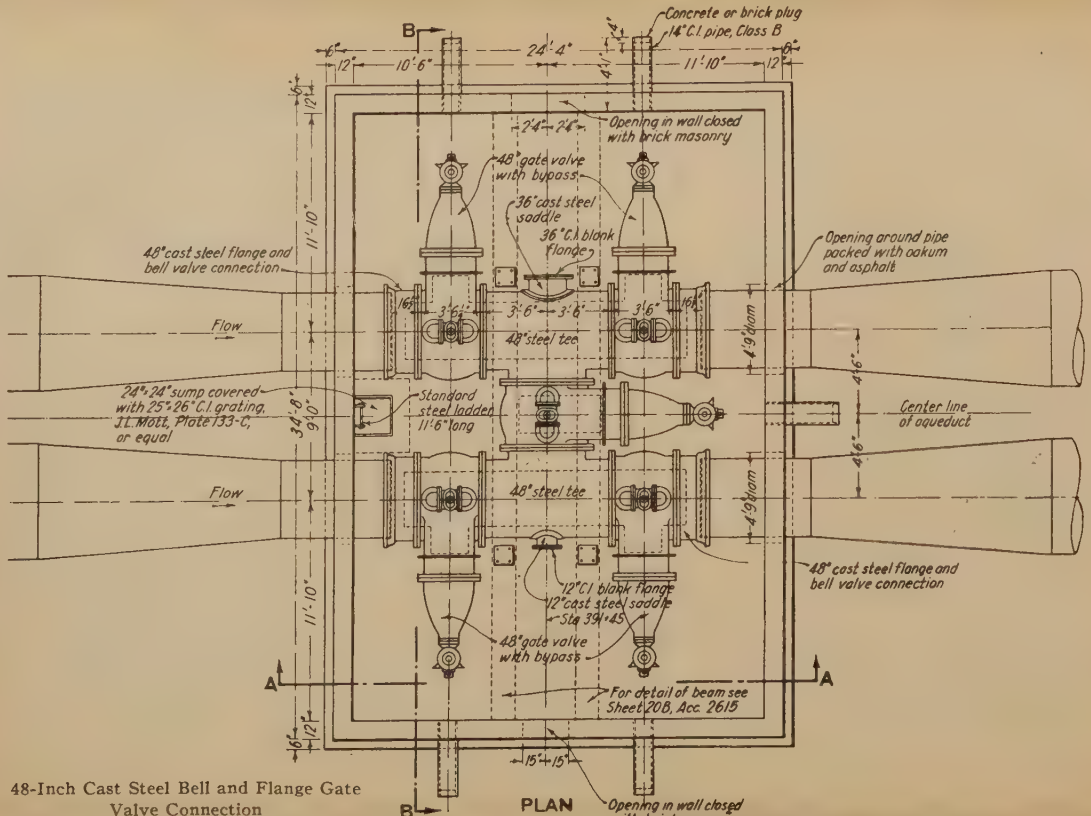
Inside Dia. of Pipe	Thickness of Pipe	Dia. of Rivets	W	A	E	N	D					T				
							C. I. Pipe Class A	C. I. Pipe Class B	C. I. Pipe Class C	C. I. Pipe Class D	C. I. Pipe Class E	C. I. Pipe Class A	C. I. Pipe Class B	C. I. Pipe Class C	C. I. Pipe Class D	C. I. Pipe Class E
24"	3/16	1/2	6	1 1/4	15/16	32	25.80	25.80	26.32	26.32	26.90	5/8	5/8	7/8	7/8	1 3/16
	1/4	5/8	6	1 3/8	1 1/8	30						9/16	9/16	15/16	15/16	1 1/8
	5/16	3/4	6	1 5/8	1 5/16	26						1/2	1/2	3/4	3/4	1 1/16
	3/8	7/8	6	1 3/4	1 7/16	24						7/16	7/16	11/16	11/16	1
	7/16	1	6	1 7/8	1 5/8	22						7/16	7/16	11/16	11/16	1
	1/2	1	6	1 7/8	1 5/8	22						3/8	3/8	5/8	5/8	15/16
30"	3/16	1/2	6	1 1/4	15/16	38	31.74	32.00	32.40	32.74	33.10	5/8	3/4	15/16	1 1/16	1 5/16
	1/4	5/8	6	1 3/8	1 1/8	36						9/16	11/16	7/8	1 1/16	1 1/4
	5/16	3/4	6	1 5/8	1 5/16	34						1/2	5/8	13/16	1	1 3/16
	3/8	7/8	6	1 3/4	1 7/16	30						7/16	9/16	3/4	15/16	1 1/8
	7/16	1	6	1 7/8	1 5/8	28						3/8	1/2	11/16	7/8	1 1/16
	1/2	1	6	1 7/8	1 5/8	28						5/16	7/16	5/8	13/16	1
36"	3/16	1/2	6 1/2	1 1/4	15/16	46	37.96	38.30	38.70	39.16	39.60	3/4	7/8	1 1/8	1 5/16	1 9/16
	1/4	5/8	6 1/2	1 3/8	1 1/8	44						11/16	13/16	1 1/16	1 1/4	1 1/2
	5/16	3/4	6 1/2	1 5/8	1 5/16	40						5/8	3/4	1	1 3/16	1 7/16
	3/8	7/8	6 1/2	1 3/4	1 7/16	36						9/16	11/16	15/16	1 1/8	1 3/8
	7/16	1	6 1/2	1 7/8	1 5/8	32						1/2	5/8	7/8	1 1/16	1 5/16
	1/2	1	6 1/2	1 7/8	1 5/8	32						7/16	9/16	13/16	1	1 1/4
42"	1/4	5/8	6 1/2	1 3/8	1 1/8	52	44.20	44.50	45.10	45.58	.....	13/16	15/16	1 1/4	1 1/2	....
	5/16	3/4	6 1/2	1 5/8	1 5/16	46						3/4	7/8	1 5/16	1 7/16	....
	3/8	7/8	6 1/2	1 3/4	1 7/16	42						11/16	13/16	1 1/8	1 3/8	....
	7/16	1	6 1/2	1 7/8	1 5/8	38						5/8	3/4	1 1/16	1 5/16	....
	1/2	1	6 1/2	1 7/8	1 5/8	38						9/16	11/16	1	1 1/4	....
48"	1/4	5/8	6 1/2	1 3/8	1 1/8	58	50.50	50.80	51.40	51.98	.....	15/16	1 1/16	1 3/8	1 11/16	....
	5/16	3/4	6 1/2	1 5/8	1 5/16	52						7/8	1	1 5/16	1 5/8	....
	3/8	7/8	6 1/2	1 3/4	1 7/16	48						13/16	15/16	1 1/4	1 9/16	....
	7/16	1	6 1/2	1 7/8	1 5/8	44						3/4	7/8	1 3/16	1 1/2	....
	1/2	1	6 1/2	1 7/8	1 5/8	44						11/16	13/16	1 1/8	1 7/16	....
54"	1/4	5/8	7	1 3/8	1 1/8	64	56.66	57.10	57.80	58.40	.....	1	1 1/4	1 9/16	1 7/8	....
	5/16	3/4	7	1 5/8	1 5/16	58						15/16	1 3/16	1 1/2	1 13/16	....
	3/8	7/8	7	1 3/4	1 7/16	54						7/8	1 1/8	1 7/16	1 3/4	....
	7/16	1	7	1 7/8	1 5/8	50						13/16	1 1/16	1 3/8	1 11/16	....
	1/2	1	7	1 7/8	1 5/8	50						3/4	1	1 5/16	1 5/8	....
60"	1/4	5/8	7 1/2	1 3/8	1 1/8	70	62.80	63.40	64.20	64.82	.....	1 1/16	1 3/8	1 13/16	2 1/16	....
	5/16	3/4	7 1/2	1 5/8	1 5/16	64						1	1 5/16	1 3/4	2	....
	3/8	7/8	7 1/2	1 3/4	1 7/16	60						15/16	1 1/4	1 11/16	1 15/16	....
	7/16	1	7 1/2	1 7/8	1 5/8	56						7/8	1 3/16	1 5/8	1 7/8	....
	1/2	1	7 1/2	1 7/8	1 5/8	56						13/16	1 1/8	1 9/16	1 13/16	....
72"	5/16	3/4	8	1 5/8	1 5/16	76	75.34	76.00	76.88	.....	.....	1 5/16	1 5/8	2 1/16	....	....
	3/8	7/8	8	1 3/4	1 7/16	72						1 1/4	1 1/16	2	....	....
	7/16	1	8	1 7/8	1 5/8	64						1 3/16	1 1/2	1 15/16	....	....
	1/2	1	8	1 7/8	1 5/8	64						1 1/8	1 7/16	1 7/8	....	....

Field Test Head

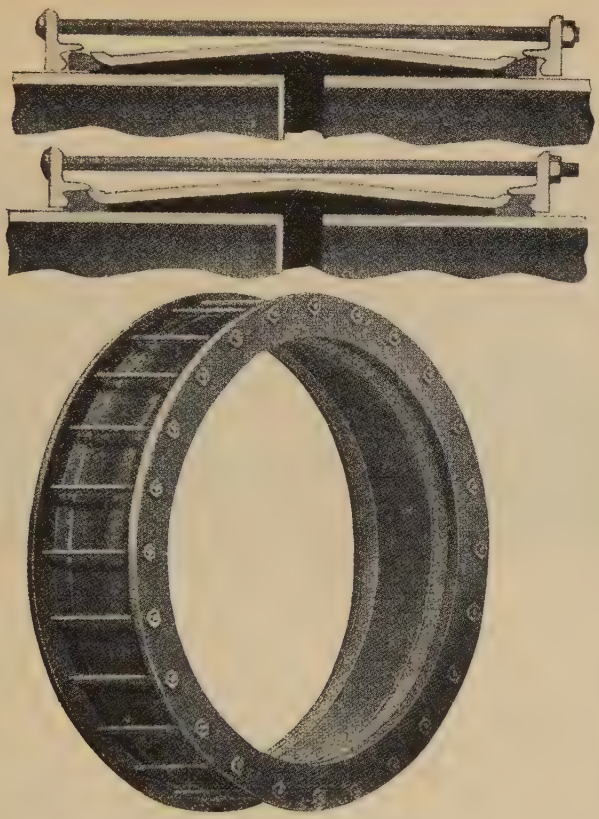
The Company is prepared to rent field test apparatus to be used by the field contractor for testing the tightness of pipe joints after riveting in the field.

This apparatus comprises a steel plate dished head riveted to a cast iron ring and provided with a rubber gasket.

This test apparatus has been widely used and has given entire satisfaction. It is built with a wide factor of safety. Modern tendency, however, is toward Dished Heads riveted in place and cut out after test.

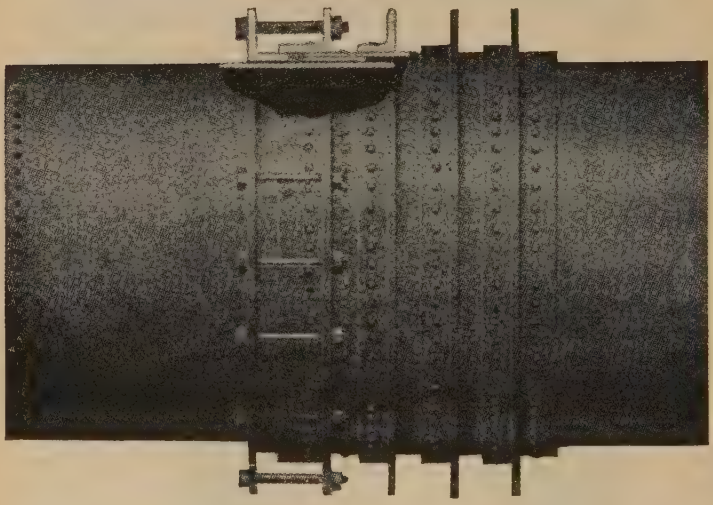

Concrete or brick plug
14" C.I. pipe, Class B
Opening in wall closed with brick masonry
48" gate valve with bypass
36" cast steel saddle
36" C.I. blank flange
48" cast steel flange and bell valve connection
Opening around pipe packed with oakum and asphalt
Flow
48" steel tee
24"x24" sump covered with 25"x26" C.I. grating, J.L. Mott, Plate 133-C, or equal
Standard steel ladder 11'6" long
Center line of aqueduct
12" C.I. blank flange
12" cast steel saddle
Sta 39+45
For detail of beam see Sheet 20B, Acc. 2615
PLAN

48-Inch Cast Steel Bell and Flange Gate Valve Connection



High Pressure Flexible Coupling
(Patented)

This joint is suitable for all high pressure work and forms a perfect expansion joint and flexible coupling, permitting deflection of the line at each joint. It consists of rolled steel follower rings, through-bolted, and seated on rubber gaskets against a steel center ring. It has given eminently satisfactory service wherever used. Especially adapted for gas lines. Advantageously used for diameters too small for riveted taper joint.



East Jersey Expansion Joint
(Patented)

An expansion joint that functions perfectly under all conditions of service. It stays tight and puts the minimum strain on the line. Two anchorage angles are shown in the above cut at the right of joint.

Wanaque Lock-Bar Steel Aqueduct

In 1927 Mr. F. Herbert Snow, Chief, Bureau of Engineering, Public Service Commission of the Commonwealth of Pennsylvania, was called in consultation by the North Jersey District Water Supply Commission on matters relating to the 74-inch LOCK-BAR steel Wanaque Aqueduct, which the East Jersey Pipe Company is now completing, and made an exhaustive report on the entire matter, including a notable chapter on hydraulics. In this deliberation Mr. Snow had the cooperation of the eminent American hydraulician, Mr. Robert E. Horton. To him Mr. Snow put the following questions:

"1. What is the proper coefficient of roughness for 'Smooth-bore' pipe, well and properly constructed, when clean and new?

"2. Assuming that the pipe will be constructed under such conditions that it may be periodically cleaned and the interior re-coated, if necessary, and thus maintained at all times in a fair condition of smoothness—what is the proper coefficient of roughness to apply to the pipe in service?"

Mr. Horton, for over 25 years familiar with Northern New Jersey conditions, reported in part as follows:

"The discussion of friction losses in the pipe line is given in terms of Kutter's coefficient of roughness, '*n*'. This is generally familiar to engineers, but it may be worth while to note at the outset for purposes of comparison, that this factor has a value of about 0.010 for very smooth surfaces, such as glass or brass pipes, and that the velocity and discharge through a conduit, other things being equal, is very nearly in inverse proportion to the value of '*n*', so that increasing the value of '*n*' from 0.010 to 0.011 corresponds to a decrease in the velocity and carrying capacity of about 10 per cent.

"Following precedent given in certain earlier reports on this subject, the expression 'smooth-bore' pipe will be here used to describe a steel conduit suitably coated in such a manner as to avoid beads and ridges in the interior coating, the pipe being without longitudinal rivets and with a single row of circumferential rivets at 30-ft. intervals along the pipe.

"The term 'smooth' pipe will be used to describe commercial pipe which has, when new, an interior surface free from projections, such as rivets and joints. This includes new, well coated

cast-iron pipe, wood-stave pipe, vitrified and concrete pipes, properly laid. In this sense 'smooth pipe' is mechanically a little smoother than 'smooth-bore pipe' owing to the circumferential rivets in the latter. On the other hand, pipe of the lock-bar type with butt-strap circumferential joints and countersunk rivet heads inside, would be a 'smooth' pipe of a high grade.

"The expression 'kind' as distinguished from 'condition' of surface will be used to describe the material from which and manner in which the interior surface of a new pipe is made.

"There is no standard mechanical scale of roughness. Quantitatively the smoothness or roughness of two pipes is expressible only in terms of the hydraulic scale or coefficient of roughness. Differences of opinion as to the proper coefficient of roughness to be applied to pipe arise partly through lack of standards for comparison of mechanical roughness and partly from different views as to the degree of mechanical roughness that will be attained by a given pipe as the result of use.

"Since discussion of this subject has centered somewhat around a table of coefficients of roughness for use in Kutter's formula[a] prepared by the writer, it will be convenient to use this table as a basis of reference and comparison.

"Relevant values of Kutter's n given in the table are as follows:

	Best	Good	Fair
Smooth lock-bar and welded 'OD' pipe	0.010	0.011[b]	0.013[b]
Riveted and spiral steel pipe	0.013	0.015[b]	0.017

"This table had its inception about 1908, at which time the writer was called upon to determine the hydraulic features of the Lockport-Rochester level of the New York State Barge Canal, an open channel having a low water slope of only 2.29 ft. in about 60 miles. The condition was so unusual as to demand a careful study of flow formulæ and coefficients. The study was gradually extended to include pipe as well as open channels. The object was to set up not only categories of kind of surface, as had been done by Kutter and Bazin, but also categories of condition, so that the expected condition in

[a] Engineering News, Feb. 24, 1916, p. 373.
King, Handbook of Hydraulics, p. 191.
Merriman, Treaties on Hydraulics, 10th ed., p. 288-a.
Kempe's Engineer's Year Book for 1925, p. 1321.
[b] Values commonly used in designing.

service and not only the coefficient of roughness when new, could be taken into account in designing. For some of the surfaces and conditions, complete or adequate experimental data were not then available, nor are they now available. In such cases consideration was given to the opinions of hydraulic engineers as revealed by their published writings, including D'Arcy, Bazin, Ganguillet and Kutter, Clemens Herschel, W. C. Unwin, Mansfield Merriman, John R. Freeman, Saph and Schoder and many others.

"Where data for a particular condition were inadequate, interpolations were made from data for the same surface in smoother and rougher conditions, or values were derived by comparison with data for other kinds of surfaces apparently having about the same mechanical roughness. The validity of such interpolations is recognized.

"The preceding statement shows that this table was not 'merely' the author's opinion, neither was it 'unsupported.' The table was intended as a convenient and condensed basis of reference. It was obviously impossible as well as unnecessary to publish in conjunction therewith the hundreds of pages of supporting data which had been gone through and studied in its preparation. The table was published in 1916. Since then many new experimental data have become available, particularly for smooth surfaces. The writer would not hesitate to change any figures given in the 1916 table which may require modification in the light of later experience.

"In fixing the values of n given for smooth lock-bar and welded 'OD' pipe given in the table, consideration was given, among other things, to the discussion of the coefficients of roughness for such pipe given in the Report on New York City's Water Supply,—Freeman, 1910 (as quoted above in your report), and it was assumed that the pipe designated as 'smooth lock-bar' pipe had butt-strap joints and countersunk interior rivet heads.

"There are various ways of arriving at the coefficient of roughness to be applied to a given conduit:

"1. To rely wholly on experiments on the same kind and condition of pipe.

"This is not in line with the principle of making use of all the available information and may lead to error. Owing to

the variations in individual experiments it is not safe to place too great reliance on a very limited number of experimental data, especially where, as in the case of many old pipes, the mechanical roughness of the pipe interior is only described in general terms.

"2. By comparison with experimental data for all kinds of pipe of similar roughness characteristics, whether of the same kind or not. Numerous experimental data on smooth pipes of different kinds indicate clearly that the material of which the pipe is constructed has relatively little effect on the coefficient of roughness provided the mechanical roughness is the same. There is strong evidence in support of the view that an excessively thin layer of fluid adheres to the wall of the pipe, limiting if not wholly eliminating the effect of differences in material on the value of n for the same mechanical roughness. It follows that experiments on a wide variety of kinds of smooth pipe can be utilized in determining the coefficient of roughness to be applied to a particular kind.

"3. By the application of recent formulæ for different classes of pipe.

"Since there is incorporated in many of these formulæ the results of nearly all relevant data for the kinds and conditions of conduit to which the formulæ refer, they are likely to be better guides to judgment than a limited number of actual experiments.

Friction Factor for Smooth Pipe

"In seeking to determine the friction factor for smooth-bore pipe which has a relatively smooth interior surface, available experimental data for smooth pipe of various kinds forms the best and most definite starting point or datum of reference, partly because of the wealth of experimental data for such pipe and partly because there can be little misunderstanding as to the degree of mechanical roughness of the pipe surface.

"Within recent years a large amount of new data has been published with reference to the friction in smooth pipes, together with reviews of the better, earlier experimental data. Reference is made particularly to the following:

The Flow of Water in Concrete Pipe, by Fred C. Scobey, Bull. 852, U. S. Dept. of Agriculture; Washington: 1920.

The Flow of Water in Wood-stave Pipe, by F. C. Scobey, Bull. 376, U. S. Dept. of Agriculture; Washington: 1916.

The Flow of Water in Drain Tile, by Yarnell and Woodward, Bull. 854, U. S. Dept. of Agriculture; Washington: 1920.

The Flow of Water through Spiral Riveted Steel Pipe, by Greve and Martin, Purdue Univ. Publications, vol. 5, no. 2, July, 1921.

Report of the Hydraulic Power Committee, National Electric Light Assoc., 1923.

"These and other publications consulted contain the results of hundreds of experiments on the friction factor in smooth pipe. As the publications are readily available it is unnecessary to repeat the tabular data here. The results are uniformly consistent, showing for smooth pipe of a variety of kinds, including wood-stave, concrete, steel flumes, clay and vitrified drain tile, and welded steel pipe, coefficients of roughness ranging in the vast majority of instances between 0.010 and 0.012 and with an average value very close to 0.011,—in fact, the proposition that n equals about 0.011 for new, smooth pipes in good condition but with a variation of perhaps 10 per cent either way, seems axiomatic. It would not have been necessary to go into this matter except to establish a basis for determining the value of n for smooth-bore pipe when new, and owing to the fact that the possibility of attaining a coefficient of roughness in such pipe when new as low as 0.013 has been questioned.

Comparative Capacity of "Smooth-Bore" and Riveted Pipe

"Data derived from experiments on riveted pipe are sometimes used for smooth-bore pipe for the reason that such experimental data are more numerous than for smooth-bore pipe. Furthermore, the assertion has been made that 'the effect of tuberculation is to nullify any difference in capacities of new pipe chargeable to the friction of the rivet heads[a]. This statement requires qualification. It would be correct to say that tuberculation tends to nullify the difference in original carrying capacity.

[a]Water Works Handbook, 3d ed., p. 765.

"On an otherwise uniformly smooth surface a comparatively small amount of roughness will produce an appreciable increase in friction.[a] For further increase in roughness the friction and value of Kutter's '*n*' increase, though probably not at a uniform rate, until finally, for a completely roughened surface, the 'worst possible condition'[b] is attained, beyond which there is no further increase in friction due to roughness *of the same kind.* If the roughness is due, for example, to tuberculation, there may still be a decrease in carrying capacity due to reduction in effective cross-section.

"For pipe with a joint and circumferential rivets at 30-ft. intervals there will be several square feet of smooth surface per rivet. For riveted steel pipe there are one or more rivets per square foot. If the pipes tuberculated equally, then when the tubercular roughness equals the rivet roughness in the riveted pipe, the total roughness, i. e., rivets plus tubercles, will still be but little more than one-half as great for the smooth-bore as for the riveted pipe. It is only when the tuberculation becomes excessive, approaching the 'worst' condition that the difference in mechanical roughness for the two classes of pipe can become approximately null. It does not follow from the preceding that the actual friction loss in the smooth-bore pipe is less than in riveted pipe in the same proportion that the rivet plus tubercular roughness is less, for the reason that a large portion of the total friction loss is due to skin friction on the smooth portions of the pipe surface in either case. However, it does not appear that experimental data derived from tuberculated riveted pipe can fairly be applied to smooth-bore pipe, especially when, as here, it is assumed that the smooth-bore pipe can and will be periodically cleaned, if and as needed, so that it will at all times be in a condition ranging from 'fair' to 'good.' Furthermore, as compared with a riveted pipe, it seems that it is easier to clean and maintain a smooth-bore pipe in good condition.

"The following citations are pertinent relative to the difference in carrying capacity between riveted and smooth-bore

[a] Saph and Schoder, An Experimental Study of the Resistances to the Flow of Water in Pipes; Cornell Univ., 1903.

[b] The fact that roughness often approaches a limiting value as time goes on is recognized by various investigators. Saph and Schoder (loc. cit.) and Lea, "Hydraulics," show that practically all experimental data for a given kind of pipe lie between two limiting lines, one corresponding to conditions when new and good, the other to this limiting condition. Creager and Justin, "Hydro-Electric Handbook," 1927, give values of "*n*" for the categories "best," "probable" and "worst."

pipe (American Civil Engineers' Handbook, Merriman, 4th ed., p. 1242):

" 'Carrying Capacity of Steel Pipe. Lock-bar steel pipe has a comparatively smooth interior and has substantially the same carrying capacity as cast-iron pipe. Riveted pipe is less smooth in the interior, the projecting rivets increasing the friction of the flowing water, and also the numerous joints in the plates with either in-and-out joints or with taper joints. For these reasons steel pipe carries from 10 to 15 per cent less water than lock-bar pipe or cast-iron pipe.'

" 'The Manual of Water Works Practice,' American Water Works Assoc., 1925, p. 291, states:

" 'Riveted pipes are rougher and have coefficients of discharge about 20 to 25 per cent. less than equal sizes of the smoother types of pipes.'

"Duran, 'Hydraulics of Pipe Lines,' 1921, p. 10, states:

" 'For riveted-steel pipe, when new, values of C may range about 110 and upward. With age the value will drop to a range usually from 95 to 100. Hazen and Williams state as a broad generalization, that steel pipe of a given size and age will carry the same quantity of water as cast-iron pipe of the same size and ten years older. With butt-strap circumferential joints, approximately flush riveting on the inside and special care to realize good hydraulic conditions, C for new pipe will rise to values about 120, falling with advancing age to values ranging from 100 to 110.'

"Creager and Justin, 'Hydro-Electric Handbook,' 1927, p. 129, give the following values of 'n':

"For smooth interior steel flumes, painted,—

Best condition	'n' = 0.012
Probable condition	= 0.013
Worst condition	= 0.017

"The 'Report of Hydraulic Power Committee,' National Electric Light Association, 1923, pp. 7-8, give the results of experiments on both welded or smooth, and riveted steel penstocks, in use on the Pacific coast. They summarize the tabulated values of 'n' as follows:

Lap welded pipe with bump joints	'n' = 0.012
Thin riveted pipes with welded joints	'n' = 0.014

"It is interesting to note that the numerous experiments tabulated show results for riveted pipes,—some after considerable use,—and all 6-ft. or larger diameters, ranging generally from 0.011 to 0.015, while the five values given for welded pipe range from 0.0111 to 0.0131.

"There are several special formulæ for computing the velocity and flow in commercially smooth pipes and in riveted pipes.

"For the purpose of comparison, computations were made to show the value of Kutter's '*n*' which if used in the Manning formula would give results identical with those given by various special formulæ for smooth and riveted pipe, respectively. The computations are based on a conduit 6-ft. in diameter with a grade of 2 ft. per mile.

"It is found that '*n*' = 0.012 in the Manning formula is equivalent to the Hazen-Williams formula for smooth cast-iron pipe with $C = 140$.

"A value of '*n*' = 0.0103 is equivalent to the Barnes' formula for new asphalted cast-iron pipe.

"Values of '*n*' between the limits 0.0093 and 0.0110 are equivalent to the Lea-King formula for smooth asphalted pipes.

"The following values of '*n*' are equivalent to the U. S. Reclamation Service formulæ for different classes of pipes:

Cast-iron	'*n*' = 0.0112
Concrete	= 0.0118
Wood-stave	= 0.0126

"A value of '*n*' = 0.0102 is equivalent to the Yarnell and Woodward formula for clay tile.

"A value of '*n*' = 0.0107 is equivalent to the Yarnell and Woodward formula for concrete drain tile.

"Computations were also made on the same basis by various formulæ intended to apply to riveted steel pipe.

"A value of '*n*' = 0.0134 is equivalent for the given conditions of the Barnes' formula for riveted steel pipe.

"A value of '*n*' = 0.0124 is equivalent to the U. S. Reclamation Service formula for riveted steel pipe.

"A value of 'n' = 0.0125 to 0.0154 is equivalent to the Lea-King formula for riveted steel pipe.

"Hughes and Safford, 'Hydraulics,' 1911, pp. 325-329, give a carefully scrutinized and selected table of the better experiments on riveted steel pipes, new and old. The corresponding values of the coefficient of roughness 'n' have been computed from these data, which cover more than one hundred individual experiments, including the Newark, and the Rochester II, conduits. These values of 'n' are commonly around 0.013 for new asphalted riveted pipes, of larger sizes and 0.013 and 0.015 for pipes in use.

"Smoothly coated lock-bar steel pipe without projecting joints or rivets is undoubtedly smoother than most classes of commercially smooth pipe of other kinds, but with circumferential rivets it is about the same as the average of other types of commercially smooth pipe, including clay and vitrified, cast-iron, wood-stave and concrete, all when new and in good condition.

"From the preceding data it is clear that the friction coefficient for riveted pipe is commonly 15- to 20 per cent greater and the carrying capacity 15-to 20 per cent less than for smooth pipes.

Decrease in Carrying Capacity

"Rules and formulæ have been devised to express the decrease in carrying capacity of water supply conduits directly in terms of age or duration of service. While such rules undoubtedly often fairly represent average conditions, the writer has little faith in their applicability to individual cases. Instances where serious impairment of conduit capacity through tuberculation, aquatic growths and deposits has taken place are, of course, familiar to all engineers. On the other hand, there are cases where the reduction in carrying capacity has been but slight, if any whatever occurred, even after a long period of years. The 25-year-old 24-inch pipe line at Hammond, Ind., may be cited as an example. This is reported to have shown a coefficient of roughness 'n' = 0.0107 or a capacity at least equal to that to be normally expected from a good, new conduit (Water Works Handbook, 3d ed., 1927, p. 758).

"In the spring of 1926 the writer examined some of the smooth, forged steel, high head, penstock lines in use in conjunction with power plants in the Sierras. None of those

examined showed any appreciable deterioration even after several years' use.

"These are perhaps exceptions and it is undoubtedly proper and desirable to make allowance for probable deterioration in carrying capacity in any proposed steel or iron conduit, but where, as here, it is the intention to keep the pipe reasonably clean and in fair to good condition and the conditions are such that this can be done, it does not seem good economy to provide conduit capacity adequate for the 'worst condition' of deterioration.

"The extent to which a given conduit will decrease in carrying capacity depends on several factors, of which the most important are:

(a) The character of the coating, and
(b) The character of the water.

Authorities do not seem to be fully agreed as to the specific effect of a given characteristic of the water conveyed as regards its effect on coatings under the accumulation of obstructions to flow in the pipe line.

"The following citations may be noted (Water Works Practice, Manual of the American Water Works Assoc., 1925, p. 291):

" 'The carrying capacity of all types of pipe becomes impaired with age. The first impairment is from filamentous vegetable organisms which quickly grow on the surfaces of pipe lines, particularly those parts nearest the sources, where the water is richer in food for plant life. More slowly there follows in the case of metal pipes, in sections of the country where the water is soft, a grosser impairment due to the formation of tubercles. These tubercles have a connection with the metal through small holes in the coating, and are composed partly of metal, but mostly of calcareous and organic matter. Blisters of raised coating are also not infrequently formed. Tuberculation and blistering are always much less pronounced and sometimes almost entirely lacking in sections of the country where the water is comparatively hard.

" 'In most locations concrete and cement lined pipes suffer less impairment in carrying capacity than do metal pipes.

" 'In softer waters and in aggressive filtered waters most of the tar and asphalt coatings for metal pipes have been

found ineffective in preserving carrying capacity and preventing tuberculation. Improved coatings having a refined coal tar base have shown decidedly better results than coatings previously tried when inspected seven or eight years after being placed in service. Such coatings are applied by a brush which gives a comparatively rough surface, the coefficient of which has not yet been measured. Similar coatings made with a refined asphalt base and applied as a dip so as to produce smooth coatings have been in use for several years. These seem promising, but have not been inspected after much service,

"Also (American Civil Engineers' Handbook, Merriman, 4th ed., p. 1247):

" 'TUBERCLES IN CAST-IRON PIPE. The carrying capacity of cast-iron pipe is reduced in course of time by the growth of tubercles upon the interior of the pipe. In a general way the capacity of the pipe, other things being equal, is reduced from this cause by as much as one per cent per annum. In small pipes the deterioration is more rapid. Generally the deterioration is less rapid with clear lake waters and more rapid with turbid river waters, and especially waters carrying organic matter. Filtered river waters act more nearly like lake waters.'

"The waters derived from the Wanaque Reservoir are relatively soft but will partake of the character of lake waters described in the last citation. They are derived, generally speaking, from a region of granite and sandy soils. For waters from a similar region in the Adirondacks the writer's experience has been that little deterioration in carrying capacity generally takes place in large cast-iron supply mains. On the other hand, he has seen both moderate and serious depreciation in carrying capacity for highly calcareous waters. Probably the softer the water and the greater its solvent power, the greater the extent to which it attacks the pipe coating. If the coating is adequately resistant, then little tuberculation may occur from a soft water. The writer is not a chemist and is disinclined to speculate as to the extent to which depreciation in carrying capacity of the suggested steel supply lines may take place, nor does it seem necessary,—

"(1) Because this report is based on the assumption that the proposed steel pipes can and will be periodically cleaned and kept in good condition.

"(2) It does not appear there is any great difference in opinion as to the percentage depreciation of carrying capacity to be provided for, if identical conditions of use are assumed.

"Messrs. Pratt and Sherrerd state, referring to a co-efficient of roughness 'n'=0.013 for smooth-bore pipe:

" 'We are of the opinion that the use of such a low coefficient is not justified even for new pipe.' They advise the use of a coefficient of 'n'=0.018 for actual conditions, assuming, apparently, that the pipe will not or cannot be cleaned and maintained continuously in fair condition. They also suggest a co-efficient 'n' =0.015 for new pipe.

"Mr. Johnson,* on the other hand, uses a coefficient of roughness 'n' =0.011 for new smooth-bore pipe and 0.013 for the pipe in service, subject, however, to periodic cleaning and maintenance of the interior in good condition.

"A comparison of these figures is interesting. In accordance with the Manning formula, which is equivalent to the Kutter formula under those conditions to a sufficient degree of accuracy, for present purposes the velocity and discharge are inversely proportional to the coefficient of roughness. Taking reciprocals of these coefficients and computing the impairment or percentage reduction in carrying capacity assumed in the two cases, the following results are obtained:

Johnson: $\dfrac{\text{New} - \text{old}}{\text{New}} = \dfrac{90.9 - 76.9}{90.9} = 15.4\%$

Pratt & Sherrerd: $\dfrac{\text{New} - \text{old}}{\text{New}} = \dfrac{66.7 - 55.5}{66.7} = 16.8\%$

It appears, therefore, that Mr. Johnson has made an allowance for 15.4% reduction in carrying capacity, assuming that the pipes would be kept in good condition, whereas Messrs. Pratt and Sherrerd have made an allowance of 16.8% for deduction in carrying capacity, assuming that the pipe would not be cleaned. The difference between these two percentages is insignificant in comparison with the percentage of uncertainty

*Consulting Engineer, New York.

as to the amount of decrease in carrying capacity which may take place in a conduit not yet constructed.

"If 0.013 is taken as Pratt and Sherrerd's limiting minimum value of '*n*' for new smooth-bore conduit, then using their value 0.018 for pipe in use, the reduction in capacity amounts to 27.8 per cent. An allowance of 15.4% reduction for pipe which is cleaned and maintained in a fair to good condition is not unreasonable in comparison with an allowance of 27.8% for a pipe which is not cleaned and which approaches the 'worst' condition as time runs on.

Applicability of The Kutter and Manning Formulæ

"While this question has not heretofore been raised in this connection, it seems proper to inquire whether the Kutter formula is the best available for application to the case under consideration and whether the coefficients of roughness given in the writer's 1916 table require revision in the light of later investigations as to the laws of fluid friction. Adequate discussion of this point would lead too far afield. However, it seems probable that friction loss for velocities above Reynold's critical velocity is a combination of loss due to laminar flow in the 'layer of shear' (G. I. Taylor) close to the pipe wall and a loss due to turbulent flow in the interior. Also that the thickness of the layer of shear decreases as the velocity and roughness increase. This may account for the apparent departure of the exponent of velocity from 2.0 in most of the recent pipe flow formulæ. The value of the exponent in the Kutter-Chezy and Manning formulæ is 2.0, while Lea, Barnes and others have found that this exponent increases from a value about 1.75 for smooth pipes to 2.0 for rough pipes.

"Recently a general formula of the type:

$$S = \frac{k\, v^m}{d^{3-m}}$$

has received strong support from the investigations of Osborne Reynolds, Stanton and Pannell, and others, the exponent '*n*' increasing from about 1.75 for smooth to 2.0 for rough pipe. We are dealing here with a relatively smooth pipe. If the correct value of the exponent is 1.75 for this pipe when new and in good condition, the above expression leads to the formula:

$$v = k' d^{0.714} S^{0.571}.$$

The experimental values of 'n' for smooth pipe are generally for pipes of smaller diameter and for steeper slopes than the one here under consideration. The use of an exponent 0.571 instead of an exponent ½, as in the Kutter-Chezy and Manning formulas, together with a value of 'n' correct for these average conditions, will lead, when applied to the relatively flat slope of the Wanaque conduit, to a slightly smaller velocity and discharge than is obtained by the Kutter-Chezy formula. The difference apparently will not amount to more than 2 or 3 per cent. when the pipe is new, and will disappear if the pipe is allowed to become rough from use. Also it may be noted that the Kutter formula was designed for open channels rather than for pipes, although its use for the latter is common and generally gives good results. Its utility for very flat slopes has been questioned. For a 6-foot diameter smooth pipe with a gradient of 2 feet per mile, the Manning formula gives a discharge about 3 per cent less than that obtained from the Kutter-Chezy formula.

"In view of the preceding and from a comparison of the results obtained by different recent formulæ for special conditions of pipes, it appears advisable in applying the Kutter-Chezy formula to the conduit in question to make a small allowance for possible error in the Kutter formula. For these particular conditions the error probably does not exceed about 3 per cent for the pipe when new.

"Furthermore, it is proper to make a small allowance for the effect of circumferential rivets as compared with a value of 'n' for 'smooth' pipe. Taking 'n' = 0.011 for a smooth pipe, with the average diameter and slope occurring in actual tests, it appears that the value of 'n' appropriate to a smooth-bore conduit of the diameter and grade under consideration should, if the pipe is well and properly constructed, lie between 0.011 and 0.012.

Conclusions

"The coefficient of roughness 'n' for a smooth-bore pipe, allowing for circumferential rivets and for possible error of the Kutter formula, should be between 0.011 and 0.012 for a new pipe, well and properly constructed.

"It is impossible to predict with certainty the reduction of carrying capacity for a conduit not built. Rules and formulæ expressing depreciation of carrying capacity in terms of age, although correct for average conditions, may fail in individual cases.

"Some allowance for depreciation in carrying capacity is necessary and desirable. When conditions permit, it is advisable to maintain the conduit in at least 'fair' condition by cleaning, when and if necessary, rather than to provide an initial capacity adequate for the 'worst condition' of a neglected conduit.

"An allowance for depreciation in carrying capacity of roundly 16 per cent corresponds to an increase in roughness from 0.011 to 0.013, or from 0.015 to 0.018 and is about the same as a depreciation in carrying capacity of Rochester's steel plate conduit II during the twenty years 1904 to 1925.

"If periodically cleaned, in case deterioration develops, it will be possible to keep the coefficient of roughness in a smooth-bore conduit at all times as low as 0.013 to 0.014."

Largest Steel Pipe Contract
ever awarded in the East

The Wanaque Aqueduct contract let to the T. A. Gillespie Company by the North Jersey District Water Supply Commission calls for an expenditure of over $5,000,000.

This was for 164,000 ft. of 74-inch Lock-Bar Steel Pipe (about 35,000 tons of steel).

There are definite reasons of economy and service why Lock-Bar Pipe has been selected for the water supply systems of scores of prominent cities and towns of the United States and Canada.

EAST JERSEY PIPE COMPANY

7 Dey St., New York, N. Y.

LOCK-BAR

Before Closing

STRONG AS THE PLATE ITSELF

Specifications for Lock-Bar Steel Pipe

(North Jersey District Water Supply Commission)
For the Wanaque Aqueduct, 32.5 miles of 74-inch pipe.

Steel Pipes

Work Included. The contractor shall furnish, lay, test and make tight the twin lines of steel pipes between the limits of the contract indicated on the drawings. Unless otherwise shown on the drawings, or ordered, pipes shall be 72, 74 and 76 inches in nominal diameter, and in exact accordance with the specifications. Also as a part of the work under this item shall be included the maintenance of hydrostatic pressure in the pipes, the removal from the pipes of water used for testing and other purposes, the cleaning of the pipes in preparation for covering or lining, the final cleaning of the inside of the steel and cast-iron pipes and the sterilization and filling of the aqueduct with clean water in preparation for placing it in service.

The price bid under the pipe items shall include all steel tees, wyes, reducers, flanges, sleeves, closing in pieces, and rivets. All steel castings for connections to manholes, blow-offs, air valves, gate valves and other connections to the steel pipes will be paid for under Item __.

Plans and Pipe Sketches. To the drawings now furnished such detailed drawings will be added as may be deemed necessary by the Engineer. A copy of the drawings and specifications shall be kept constantly on the work by the Contractor or his representatives. Before beginning to fabricate the pipe the Contractor shall submit for approval the sketches of the proposed pipe and fittings in detail and shall secure the Engineer's approval before proceeding with fabrication.

Materials and Workmanship. All material must be of the best of the respective classes, and all work must be done in a good and substantial manner by skilled workmen, subject to the inspection and approval of the Engineer or his representative, and the Contractor shall cause the details of the work to be executed in strict conformity with the drawings and specifications. The incorporation in the work of foreign or imported materials, as constituting a possible cause for delay, difficulties of inspection and rejection, will not be permitted.

INSPECTION. The inspector representing the Engineer shall have free entry, at all times while work on the contract is being performed, to all parts of any mill, shop or factory where material herein specified is being produced. The Contractor shall afford the inspector, free of cost, all reasonable facilities to satisfy him that the material is being furnished in accordance with these specifications. Tests will be made at the place of manufacture prior to shipment whenever practicable, and will be so conducted as not to interfere unnecessarily with the operation of the works. The Engineer shall have the right to make chemical and physical tests of materials, and to reject material, either finished or unfinished, which does not conform to the specifications. Any material which shows injurious defects subsequent to its acceptance at the place of manufacture will be rejected.

MANUFACTURING. The shearing, scarfing, punching, reaming, fitting, riveting, caulking and other shop operations shall be done in accordance with the best shop practice. The pipes shall be of taper section, manufactured in 30 foot lengths unless otherwise required to fit special conditions and where abrupt changes of line and grade occur. The minimum inside diameter of the pipe, measured to the plate, shall be in accordance with the nominal diameter specified. The work shall be carefully and accurately laid out and all rivet holes shall be spaced with precision. Holes shall be drilled from the solid or punched to an approved size and reamed. Punched holes shall be clean cut, without torn or ragged edges, and in punching only the best and sharpest punches and dies shall be used. All burrs or splits caused by punching shall be removed by suitable means. Corresponding holes shall, without enlarging, coincide to within about 1/32 inch, and all plates in which corresponding holes do not so coincide shall be rejected, unless the Engineer shall be of the opinion that the conditions of stress are such at the point in question as to make a more extensive enlargement safe. Drift pins shall not be used in forcing holes, but any perceptible lack of coincidence in acceptable plates shall be corrected by a sharp reamer or drill.

TYPES OF CIRCUMFERENTIAL JOINTS. The pipes shall be fabricated with lap-riveted circumferential joints for connection in the field, and the contractor shall submit for the Engineer's

approval, sketches showing type and rivet spacing at the time of submitting pipe sketches. Circumferential joints on the bridge crossing, and at such other places as directed, shall be double riveted.

Changes in Alignment and Grade. The contract drawings give the alignment and grade of the pipes based upon the present knowledge of existing conditions, and the work will be laid out approximately as there shown. However, corrections in alignment and grade may be necessary as further information is gathered in the field and as the trench is excavated, and test-pits will be ordered in advance if thought necessary to minimize these corrections; but no alterations of pipes, either in the shop or in the field, due to such changes shall constitute a basis for a claim for additional payment, but shall be considered as having been included in the prices stipulated for the various items of the contract.

Where angles and curves occur in the alignment and grade of the pipe line the plates shall be cut and punched to the required lines for forming a slight oblique angle at the circular seams of as many courses as may be necessary to produce the required curvature or deflection. This angle must not exceed 7½ degrees on any shop joint or 5 degrees on any joint made in the field.

Closures. In order to facilitate laying, testing and the placing in exact location of the curves and special work, sufficient closures shall be provided and not fabricated until the exact required length can be ascertained.

Lock-Bar Pipe. Lock-Bar Steel Pipe shall be made of steel plates conforming to specifications, connected by steel lock bars forming the longitudinal joints, and with riveted connections for the circumferential joints. The pipe shall be of taper section, and each section shall be approximately 30 feet long except in special cases where required to fit special conditions or where abrupt changes of line or grade occur.

The longitudinal edges of the plates shall be planed and upset to a sufficient degree to form the necessary shoulder for engaging the lock bar. The small end of the taper section shall have the full inside diameter specified.

The plates shall be trued, punched and beveled by sharp clean punches and dies, leaving clear holes without burrs. Holes for field riveting shall be carefully spaced, each end of the section of pipe being punched for the proper number and sizes of rivets called for on the plans. The diameter of rivet holes shall exceed the diameter of rivets 1/16 inch.

The plates shall be crimped to prevent damages to the upset edges in the rolls and then cold rolled to the radius of the cylinder of the pipe. The lock-bars having previously been scarf milled at opposite ends shall be applied to one plate, the companion lowered into the lock-bar and the plates drawn together by steel clamps. The pipe shall then be placed in the pressing machine and the lock-bars pressed down over the upset edges of the plates by hydraulic pressure. After the bars have been pressed, the ends shall be trimmed to conform to the bevel of the edge of the plate.

Steel for plates, rivets and lock-bars shall be made by the open hearth process. Plate steel shall be standard specification for Boiler and Firebox Steel—"Flange" Quality—A.S.T.M. serial designation A30-24.

Steel for lock-bars shall conform to the following specifications:

Quality	Open hearth—extra dead soft steel.
Tensile strength	40 to 50 thousand pounds.
Elastic Limit	One-half of the ultimate tensile strength.
Elongation	Not less than 28% in 8 inches (but need not exceed 30%).
Reduction Area	50%.
Cold Bend Test	180 deg. flat without signs of fracture on outside.
Discard	25%.
Special Notes—	Bars must withstand severe transverse bending.

Bars must be rolled straight and true and later straightened if necessary.

Ends must be saw cut—not sheared.

Bars shall be bundled—securely fastened with four steel tie bands to prevent bending in transit.

Drop and Grout Holes. Each length of pipe shall have a hole two inches (2″) in diameter tapped with a screw thread and closed with a malleable iron plug near one end for the purpose of passing rivets into the pipe during field riveting; in addition, steel flanges, tapped for pipes not larger than 2½ inches, shall be provided in the tops of the steel pipes to be lined with mortar by the grouting method. These flanges shall be, as nearly as practicable, at the up-hill end of each course in order to prevent the formation of air pockets during the placing of the mortar lining. After the lining has been completed, these openings shall also be closed, when directed, by threaded cast-steel or acceptable cast-iron plugs of approved design. The cost of furnishing and placing holes, flanges and plugs shall be deemed to be included in the unit prices stipulated for Item ___.

Manholes. The Contractor shall place manhole saddles at such places as are shown on the drawings or where directed by the Engineer. These saddles shall be eliptical in shape, 14 in. x 16 in. inside dimensions of opening. Details of saddle to be provided will be shown on the drawings. Each saddle shall be provided with a corrugated sheet lead or copper gasket, of suitable thickness to insure a water tight joint and will be paid for under Item ___.

Cast Steel Saddles. The Contractor shall furnish and install cast steel saddles for the attachment of air valves and blow-offs. Details will be shown on the drawings. These saddles shall be riveted on the pipes after the latter are laid, and will be paid for under Item ___.

Air Valves. Air valves are to be placed on the pipes at summits or where directed. These valves shall be "Rensselaer Automatic Cluster Air Valves," combined with lever and float attachment for "air pocket" control (Fig. 77, List No. 40, Rensselaer Valve Co.) or equal. Between these valves and the

steel casting on the pipe there shall be installed a suitable double flanged gate valve, depending on the size of the air valve. Valves will be paid for under Items ..... and ___.

Blow-Offs. Blow-offs are to be placed at the bottom of the pipe at depressions as shown on the profiles or as directed. Each blow-off shall be connected by cast-iron bell and spigot pipe to the point of discharge. Blow-off valves and cast-iron pipe will be paid for under Items ___, ___ and ___.

Hydrostatic Shop Test. Each section of pipe after completion and before coating, shall be subjected to the following hydrostatic pressure test conducted in a regulation testing machine satisfactory to the Engineer.

60″ x 7/16″	175	lbs.	per	square	inch.
72″ x 3/8″	150	"	"	"	"
72″ x 7/16″	175	"	"	"	"
72″ x 1/2″	180	"	"	"	"
74″ x 3/8″	150	"	"	"	"
78″ x 1/2″	180	"	"	"	"

During the test which is to be conducted in the presence of the inspector, and while the above pressures are being applied, the longitudinal joints, whether hammer welds or lock bars, shall be violently struck at intervals of about six feet with a ten pound steel maul at a full arm swing. The pipe shall be absolutely tight throughout this test, and any pipe showing signs of leakage not easily repaired, or defects too serious for correction in the opinion of the Engineer, shall be rejected.

Cleaning. Before pipe sections are coated they shall be thoroughly cleaned of all mill scale, grease, oil, paint, rust or other foreign material, both inside and out, by wire brushing and scraping immediately before heating and also upon removal from the oven; and while the pipe is suspended in a vertical position it shall be hammered with a ten-pound sledge hammer in order to free all loose dust or scale.

Coating. After the above described cleaning and inspection, which must be done under cover, every pipe shall be heated in a suitable oven to a temperature of 350 deg. F., after which the pipe shall be coated with Hermastic Coating as manufac-

tured by Wailes Dove-Hermiston Corporation, 17 Battery Place, New York, N. Y., "Ovarco" Pipe Coating, as manufactured by the Ohio Varnish Company, Cleveland, Ohio, or such other material equal thereto and satisfactory to the Engineer.

The coating must be free from blisters and bubbles and must not be affected by exposure nor the action of soil or water. It must strongly adhere to the pipe under all circumstances and must not become soft enough to flow at a temperature of 180 deg. F., nor brittle enough to crack or scale off at freezing temperature. The pipes shall not be coated until examined and approved by the inspector immediately before the process of coating begins. They shall be dipped vertically into the bath of pipe coating heated to a temperature of 400 deg. to 450 deg. F., and the dip shall be heated by other means than a direct flame on the dipping-tank. The pipe shall receive a uniform coating, approximately 1/32 inch in thickness. While in the bath, the pipes shall be so manipulated or redipped in accordance with the directions of the inspector, as to give a perfect and sound coating of the specified thickness. After removal from the dipping tank, they shall be set vertically while cooling.

The materials for coating, the appliances and methods of heating and applying the coating, shall be subject to the approval of the Engineer or his duly authorized inspector. In case the coating on any pipe is found defective, it must be removed and carefully cleaned and redipped.

Wrapping. After the coating on the pipes has sufficiently set they shall be further protected with a spirally wound felt fabric as follows:

Wrapping shall be done with "Soil Proof Pabco" wrap, manufactured by The Paraffine Companies, Inc., of San Francisco, Cal. The covering shall be of felt, which has been thoroughly saturated with a high melting point bituminous compound, containing not less than twenty-five per cent. (25%) by weight of an alkali-resisting mineral. The saturated felt shall weigh not less than three and six-tenths (3.6) pounds per square yard. Flaked mica shall be applied to the side of the coating which will be on the outside of the pipe, in such quantities as to give the best results.

Method of Application. This covering is to be spirally wrapped upon the pipes under a tension of not less than fifty

(50) pounds per eighteen (18) inch width of wrapping. The ends of the wrapping at the joint connections are to be finished off by sealing with dip. During wrapping of the pipe, dip shall be poured continuously as the pipe is rotated, in such quantities as to firmly and truly seal the wrap to the surface of the pipe at all points. The adjacent wraps shall lap sufficiently to obviate any possibility of bare pipe being exposed between wraps.

Protection of Pipes to be Lined with Mortar or Covered with Concrete. To protect from the effects of weather exposure the surfaces of the pipes which are not coated and wrapped at the shop, the steel surfaces when satisfactorily clean shall be coated as hereinafter specified, or otherwise acceptably treated. Interior surfaces shall be covered, by brushing or other satisfactory means, with a heavy coat of lime whitewash made as follows: to 50 gallons of heavy lime whitewash add 20 pounds of glue dissolved in water and 50 pounds of Portland cement. The exterior surfaces of the pipes shall be covered thoroughly with boiled linseed oil, by spraying or other effective method. Dirt and other foreign matter, including all objectionable rust which may form in spite of the protective measures, accumulated during transportation, storage or otherwise, shall be satisfactorily removed and the contact surfaces of the steel pipes shall be thoroughly cleaned before the joints are made up. The whitewash on the inside of the pipes must be thoroughly removed before the mortar lining is placed.

Marking. Each steel pipe and fitting shall have conspicuously painted in white on the inside after coating, a serial number for the purpose of identification. The Contractor shall furnish the Engineer with a duplicate list of pieces in each shipment, giving the serial number and designation of each pipe and fitting sent at that time, which must be certified before shipment by an inspector appointed by the Engineer.

Loading and Transportation. After the coating has become sufficiently hard, the pipe shall be loaded on suitable cars or trucks provided with wood saddles, cut to proper radius for pipe to rest on. All saddles or supports, as well as all side stakes on cars which come in contact with pipe, shall be protected with pads of burlap or other suitable material of sufficient thickness to prevent rubbing or chafing of the coating. The

entire load to be blocked and secured in the best possible manner to prevent as far as possible shifting in transit, and injury to the coating.

During loading, transportation and unloading, more than ordinary care shall be taken to prevent injury to the pipes. Loading and unloading shall be done carefully, with each pipe at all times under perfect control. Under no circumstances shall a pipe be dropped. In case any pipe receives any indentation or deformation, it shall be returned to the proper shape by satisfactory methods if such repairs can be made acceptably; otherwise, it shall be replaced with a new pipe at the expense of the Contractor. The delivery of pipes to the work shall be as required.

Rivets. All rivets shall be of steel manufactured by the open hearth process. The steel shall conform to the standard specifications for boiler rivet steel as adopted by the American Society for Testing Materials, A31-24, and be subjected to all tests and inspections provided. All rivets shall be perfect in form and when driven, they shall completely fill the holes and have heads of proper form and size, free from checks and cracks and truly concentric with the shank. Rivets of extra length shall be used where necessary.

Transportation and Hauling. If the pipes and specials are to be transferred from cars to trucks or wagons for delivery to storage yards or alongside trench they shall be carefully blocked and protected from chafing by pads of soft material. In handling extreme care must be exercised. Pipes shall be lifted by derricks or unloaded by rolling down skids and at no time shall they be dropped, skidded or dragged in any manner.

Distribution of Pipe. The pipe shall be so distributed along the line that it will be subjected to the least possible moving before laying. It will be unloaded in such a manner as not to require reversing end for end before laying in the trench. Pipe which for any reason requires moving longitudinally along the trench shall be reloaded and delivered in its proper location. In all operations the utmost care shall be exercised in order to prevent injury to the coating.

Repairing Pipe Coating. The coating and wrapping of any pipe injured in transportation shall be repaired at the Con-

tractor's expense before being put in the trench, and such pipe as is not, in the opinion of the Engineer, in suitable condition, shall be removed from the work. Where the coating or wrapping has been injured or abraided, such places shall be carefully scraped and cleaned by the use of scrapers, and wire brushed, and the coating then renewed by applying one brushed coating of priming solution, cold, followed by one brushed coating of heavy "Hermastic," "Ovarco," or equal field coating, which will be applied cold at all temperatures above forty (40) degrees Fahrenheit, and will require slight warming when applied at temperatures below forty (40) degrees Fahrenheit. This method of coating shall apply to the circular field seams and special connections.

Pipe Laying. After the trench has been excavated, as required, the pipes, specials, gate-valves, and other appurtenances shall be delivered at the site and placed as soon as practicable in the trench.

For pipe laying suitable derricks and slings shall be provided and the pipe handled in such a way as to cause no damage to the coating. The end of each pipe shall be carefully scraped inside and outside and the coating entirely removed for a distance of about three inches in order to insure perfect contact of plates. Rivet holes shall be thoroughly cleaned. Pipe shall be adjusted to line and grade and rivet holes shall be faired. When laid the pipes shall be pinned and bolted together with sufficient bolts to prevent them from pulling apart before riveting. Before pipes are laid the trench shall be excavated to grade and must be free from water. No blocking shall be left under any pipe except at the direction of the Engineer.

Field Riveting. After placing the pipes in the trench, each field joint shall be made up promptly and riveted without delay. The Contractor shall provide an adequate force of men and appliances to meet this stipulation. Pneumatic hammers and suitable buckers-up shall be used for field riveting unless otherwise approved. Every reasonable effort shall be made to keep the pipes as nearly round as practicable and internal bracing of approved type shall be used, if necessary, to prevent a greater difference between horizontal and vertical diameters than 3 inches after the trench is refilled.

Before riveting, plates shall be laid up and bolted securely together. Rivet holes which are slightly unfair shall be reamed with a taper reamer. Field rivets shall be driven by air tools from the outside of the pipe. Tools for holding on shall be applied inside the pipe. Care shall be exercised in passing rivets through the drop holes not to injure the coating.

Field rivets shall completely fill the holes in which they are driven and shall have perfect heads. All loose rivets, or rivets with imperfect heads, shall be cut out and replaced.

Field Caulking. Immediately following riveting, the pipe shall be properly caulked both inside and outside in a workmanlike manner by approved pneumatic tools. Round nosed tools only shall be used and no split caulking will be allowed. As soon as caulked, the joint inside and outside shall be coated with field coating as specified in Section ___.

Protection of Pipe and Coating. The Contractor shall at all times take every precaution to prevent injury to the coatings of the pipes and appurtenances by workmen or trespassers. During the laying, riveting, and caulking of the pipe, or at any other time while it is exposed, no person wearing boots or shoes with protruding nails or other attachments that will injure the coating shall be permitted to walk on or in the pipe. Employees working in the pipes shall wear rubber soled shoes. Dropping of tools, rivets and other materials on the pipes, dragging of heavy objects over them, and other acts that would mar the coating, shall be prevented. Pipes stored at the site of the work shall be protected in a similar manner.

Backfilling Between Bell Holes. As soon as the pipes are laid and permission given by the Engineer they shall be backfilled between bell holes to a depth sufficient to protect them from the heat of the sun and from injury by contraction or expansion due to variation of temperature.

As the work on the pipe progresses it will be examined by the Engineer, and under his direction the pipe shall be thoroughly cleaned on the inside of all debris accumulated during construction. All defective caulking shall be remedied, imperfect rivets replaced and coating renewed where found necessary.

Field Test. After the pipe has been laid, riveted, caulked, coated and backfilled between bell holes, it shall be blocked at

the ends of convenient sections of such length as the Engineer may direct, and subjected to a hydrostatic test. In no case shall the test pressure in any portion of the section tested be less than 125 pounds per square inch. The Contractor must find his own ways and means and all labor and appliances and material for testing, and must furnish the dead caps or plugs necessary for closing all openings in the pipe. The water for this testing must be furnished by the Contractor, but at such points where water may be taken from the present conduits it will be furnished without charge, provided such water can be spared. The Contractor shall pay the cost of tapping the conduits, and shall furnish and lay all necessary piping at his own expense, under the direction of the Engineer.

Before the field test is made on any section of the pipe all bell holes must be cleaned out and pumped dry in order that careful inspection may be given each joint; and when under test pressure any leakage shows, caulking must be continued until the pipe is tight.

The closing of pipe ends and all openings must in all cases be absolutely tight to prevent filling the trench with water. Should any pipe special or appurtenance break under test they must be replaced by the Contractor at his own expense, and should such break occasion collapse or damage to other portions of the line under test, the Contractor must replace such damaged pipe, and all costs of such replacement shall be borne by the Contractor.

Floating. The Contractor shall take every precaution against the floating of the pipes due to water flowing into the trench, or through flushing or puddling. In case of such floating he shall replace the pipes at his own expense, making good any injury or damage which may have resulted.

Allowable Leakage. The maximum allowable leakage shall be one hundred gallons per twenty-four hours per inch of diameter per mile of pipe, under specified test pressures.

Painting Field Joints. After the field joints have been made, caulked and tested to the satisfaction of the inspector, they shall be coated as specified in Section __. The coating shall be applied with a brush until a thickness equal to the dipped coating is attained.

Wrapping Field Joints. A strip of "Soil Proof Pabco" covering long enough to give a six (6) inch circular lap and a six (6) inch longitudinal lap is to be furnished with each section of the pipe, together with the necessary coating for wrapping the field joints. These strips shall be carefully applied to the circumferential joints, when and as, directed by the Engineer.

The wrapping of all field joints must be inspected by a duly authorized representative of the Engineer, and any joints wrapped without this inspection will not be accepted.

In case of leakage in the pipe after filling with water, and the loosening of any portion of the wrapping, the contractor shall remove enough of the wrapping to thoroughly caulk the leak, and strips of new wrapping shall be applied in a similar manner.

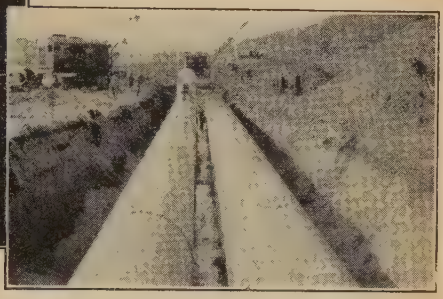
Before the final filling of any section of the pipe-line preparatory to placing it in service, the inside of the pipes shall be thoroughly cleaned and all abrasions or other damage to the coating repaired.

Maintaining Pipes Under Pressure. In addition to the requirements for field testing stipulated in Sect. __, the Contractor shall fill with water and maintain under hydrostatic pressure any portion or portions of the whole of the pipe-line as frequently, and at such times and for such lengths of time, as are directed by the Engineer, to keep the pipes as closely as practicable to a circular cross-section and unchangeable in shape when concrete is being placed about the steel pipes under Item _, when back-filling is being rammed or puddled and until it is acceptably consolidated, and when loads, other than from back-filling would, in the opinion of the Engineer, unduly distort the pipes; and he shall likewise remove such water when and as directed. The water pressure required shall be such as, in the opinion of the Engineer, will serve the purpose desired.

Filling and Sterilization of Conduit. Upon the completion of the final cleaning of the interior of the pipes in any section of the aqueduct, the making of all repairs to the coating and mortar lining, and the satisfactory completion of other work in connection with the laying of the steel and cast-iron pipes, and the construction of the connections and appurtenances, the Contractor, when and as directed, shall fill that section of the aqueduct with clean water, and shall sterilize the interior of the

aqueduct preparatory to placing it in service. Into each such section of the aqueduct as it is being filled, the Contractor shall put chlorinated lime, generally known as "chloride of lime" or "bleach," of approved quality as directed. The chlorinated lime shall be mixed with water in a satisfactory container to a suitable consistency and poured through the line manholes into the pipes, or through openings in the cast-iron pipe connections as directed. Unless otherwise ordered, the quantity of chlorinated lime used for any section of the conduit shall be at the rate of 2½ pounds of chlorinated lime for every 100 linear feet of 72-inch pipe-line with suitable allowance for the cast-iron pipe connections. If the first filling and sterilization prove unsatisfactory, the operation shall be repeated until the water in the aqueduct is acceptable for domestic use. The work of filling the aqueduct, and the cost of furnishing and placing the chlorinated lime, shall be included in the price stipulated for Item __.

Measurement and Payment. The quantity of steel pipe to be paid for under Item ..... shall be the total number of feet of pipe, actually laid in the work, of each of the various diameters and thicknesses called for on the drawings, or ordered, measured along the axis of the pipe-line after laying. The measurement shall be to the ends of the steel pipes, including the extensions into the cast-iron bells or other fittings. All reducers or steel pipe specials shall be paid for as if they were of the size of the larger pipe they are joined to. Payment will be made at the appropriate price stipulated in Item __, which price shall include all labor, materials and expenses necessary for furnishing and laying the steel pipes, for doing all cleaning, coating, wrapping and repairing of coating and wrapping, for filling the pipes with water and providing same, for maintaining hydrostatic pressure for testing and other purposes, for removing the water after testing and other operations, for performing all other work necessary to the completion of the steel pipes in the manner specified, except such work on connections as is specifically included under Item __, and that provided for in other items of the contract; for cleaning the inside of the steel and cast-iron pipes, and for sterilizing and filling them with water in readiness for placing the aqueduct in service.



25 Years' Satisfaction everywhere on the continent is your GUARANTEE that this joint is strong as the plate itself

Twin 74-inch Lock-Bar Steel Pipe line for Wanaque Aqueduct, North Jersey, the largest steel pipe contract for water supply ever awarded in the East.
In the photo to the left you can see just how the inside of Lock-Bar Steel Pipe looks.
Note the two Lock-Bar longitudinal joints and the smooth interior.
No adhesive growths can form on this glass-like surface.

IMPORTANT cities from coast to coast and from Hudson Bay to the Gulf have been installing Lock-Bar Steel Pipe for the past 25 years. The final test—the test of service—is behind, not ahead of Lock-Bar Pipe . . . And what does it show?

It shows that Lock-Bar is absolutely dependable.

In choosing pipe, select steel for "strength and security" . . . but make it Lock-Bar because only Lock-Bar gives you 100% of this strength and security . . . since the Lock-Bar Joint is strong as the plate itself.

EAST JERSEY PIPE COMPANY

7 Dey Street, New York City

LOCK-BAR

Before Closing

STRONG AS THE PLATE ITSELF

Strength of Pipe

The number of breaks recorded in large cast-iron mains, with the disastrous attendant results, induced some engineers whose minds were open to conviction, and who were willing to depart from precedent, to look for a type of pipe that would preclude the possibility of a continued recurrence of this tendency towards sudden and unexpected pipe rupture. Naturally wrought iron and steel suggested themselves. Not merely the greater tensile strength but also the ductility, higher elastic limit, and generally increased reliability in their predeterminable ability to resist rupture within fixed and definite limits, were potent factors in commending these materials. Because of the advancing trend of manufacturing technique, steel plate has become the metal commercially available.

In strength LOCK-BAR STEEL PIPE outranks pipe of any other character. All steel pipe is stronger than cast-iron pipe. The former is flexible, the latter is brittle. As a result a blow which would break cast-iron pipe merely dents steel pipe.

Wood stave pipe depends for strength upon steel hoops or bands, which hold it together. More steel is required for the hoops or bands than for a continuous plate, in pipe of equal strength.

The strength of steel pipe is equal to the strength of the longitudinal joints. Single riveted joints have an efficiency of 48% to 60%. Double riveted joints, 68% to 74%. Welded, 90%. LOCK-BAR joints, 100%.

Steel pipe, having much strength as a continuous beam, will generally stand much abuse in the matter of insecure foundations and washouts beneath the pipe. Cast-iron and concrete with lead joints will not stand washouts nearly so well.

In the larger sizes for service at relatively high pressures, steel plate pipe has been growing in use. Its advantage lies in avoidance of danger of sudden rupture.

Resistance to the effects of subsidence, distortion and shocks, or to the weight of any abnormal traffic passing over the pipe. LOCK-BAR STEEL PIPE may bend or flatten, but will not break and so cause leakages which probably would have very serious results and necessitate expensive repairs.

LOCK-BAR pipes are supplied in lengths up to 30 ft. This means fewer joints to make and maintain.

A single or double riveted seam in tension does not develop the strength of an unpunched plate.

LOCK-BAR pipe possesses far greater strength for the same thickness of plate than riveted pipe. The LOCK-BAR will produce a joint as strong as the plate itself.

Mr. D. G. Thomas, in 1912, as Chief Engineer of the Denver Union Water Company, wrote:

"* * * none of our steel pipe burst during the flood referred to in the newspaper clipping. We had several breaks in cast-iron pipes crossing Cherry Creek, which stream was the one in flood at that period.

"The Lock-Bar Steel Pipe crossing Dry Creek, which was also in flood at about that time, was subjected to a very severe test, and I am enclosing you herewith photograph showing the wreckage lodged against the Lock-Bar pipe which we purchased from you a few years ago, which pipe is located in the conduit, designated by our Company as Conduit No. 6.

"We are also enclosing you photographs showing the construction of the 60″ Lock-Bar pipe, crossing the South Platte River, which will explain themselves."

In the Fall of 1903 a severe flood occurred in the Passaic Valley district, and the records of the Board of Street and Water Commissioners of Newark, New Jersey, furnish the following interesting information on the strength of steel pipe under very adverse conditions:

"Engineer M. R. Sherrerd, of the Water Department, reported regarding the extent of the damages caused by the flood at the Pequannock watershed and along the Newark Pipe Lines in the Passaic Valley. The most threatening danger to the pipe lines occurred about a mile and a half below the Macopin Intake, where the two lines of 48-inch riveted steel pipe were left suspended in the air for a distance of about 35 feet, caused by the washing out of the lower portion of one of the abutments to a culvert under the pipe lines. The waterway of this culvert, about 10 x 14 feet, ordinarily sufficient to take the flood flow of a small mountain stream passing under the pipes

at this point, became blocked with trees which were uprooted by the torrent caused by the breaking of a dam on a small pond on this stream. Not only were these trees, some thirty in number, washed down the steep side hill and piled on the pipes, but the masonry of the upper portion of the abutment was also resting across the two pipes where the washout occurred. One line showed a slight weeping, while the other, apparently, was not in any way affected. Both lines at the time were carrying, approximately, their full capacity, and the weight of the water in the pipes, without the superimposed load, would have been sufficient to have broken cast-iron pipe.

"The engineer stated that the results of the flood showed conclusively the necessity of the new storage reservoir, with its ample capacity of 700 million gallons and its seven miles of independent 60-inch steel pipe line, which are now being constructed, as well as the advantages of the use of steel pipe lines for these long conduits over cast-iron, as the latter would not have withstood the washouts in the manner the steel pipes proved able to do."

As Chief of the Bureau of Water, Philadelphia, Pa., Mr. Fred C. Dunlap, under date of August 7, 1908, wrote us as follows:

"Complying with your request for an expression of my opinion of the strength, carrying capacity and durability of Lock-Bar Steel Pipe compared with riveted steel pipe, I would say that the City of Philadelphia has completed the installation of some 54,000 feet of 48-inch and 36-inch Lock-Bar Steel Pipe which was laid under most adverse circumstances, and I believe this pipe to be from twenty to thirty per cent stronger than double riveted pipe made of the same thickness of plate, because double riveted joints, such as are generally used in the manufacture of riveted steel pipe, have from twenty to thirty per cent less tensile strength than the plates thus joined, while tests have shown that Lock-Bar joints, when properly made, to have strength equal to the plates themselves.

"The natural life of Lock-Bar Steel Pipe is undoubtedly greater than that of ordinary riveted steel pipe similarly coated because it is made with smooth, continuous inside surface, with circular joints at thirty feet intervals only and few projecting rivets, while riveted steel pipe has circular joints at

least every seven and one-half feet and many projecting rivets, and at each the coating, which prolongs the life of steel, is more easily torn or worn off, thus exposing the bare metal to corrosive action, and further on account of the fewer number of joints and fewer rivets the leakage of the Lock-Bar Steel Pipe is less than that of the ordinary riveted steel pipe."

Colonel Theodore A. Leisen, in his paper "Steel Pipe for Large Water Mains," read at the 1922 Annual Convention of the American Water Works Association, says:

"The greatly increased number of rivet heads and lap joints form obstructions which impede the smooth flow of water, reducing the velocity, and in the same ratio the capacity, while the riveted longitudinal seams develop only about eighty per cent. of the strength of the plate. * * * Lock-bar pipe presents a smooth, unbroken surface for the full length of the sections, which under recent methods of fabrication need not be less than 30 feet in length, and, depending somewhat on the type of joint, little or no impediment to the normal flow of water is apparent. The lock-bar joint for lateral seams develops the full strength of the plate."

Similarly, Mr. Edwin A. Fisher, in recommending LOCK-BAR PIPE for a 9-mile water main in Rochester, says (Engineering News-Record, July 8, 1926):

"A single riveted seam in tension can have but 55 per cent. of the strength of the unpunched plate. A double riveted seam has about 70 per cent., whereas the lock-bar joint develops 100 per cent. the strength of the plate."

Further testimony on the strength of LOCK-BAR STEEL PIPE is furnished in an article, "An Interesting High-Pressure Test of Large Pipe."—Eng. News-Record, Vol. 61, No. 15, P. 420. At Springfield, Mass., a hydraulic test was run on a section of 42-in. LOCK-BAR STEEL PIPE, with a plate thickness of 7/16-in. The hydraulic pressure was carried to 1,050 lbs. per sq. in., which means a tension of 50,400 lbs. per sq. in. of metal. The article states:

"The test was stopped by leakage at the points where the pressure gauge pipe and the inlet pipe were attached, and it was found that the plates had stretched over 4 inches in circumference without injury to or leakage along the lock-bar joint."

Lock-Bar Steel Pipe

Determination of Strength and Coefficients of Flow

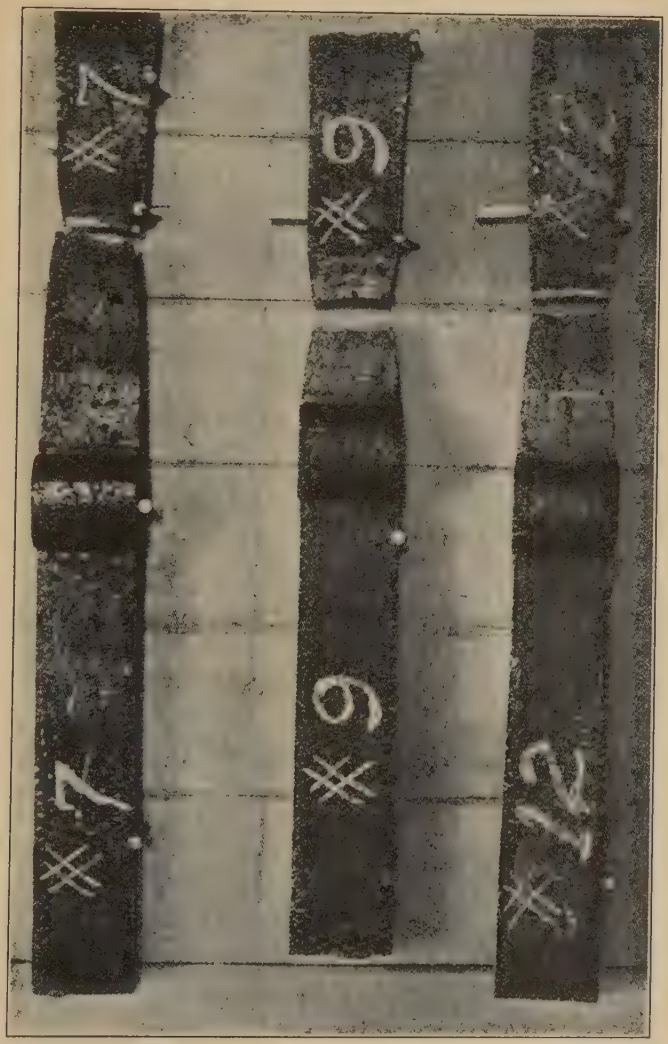
By J. B. LIPPINCOTT
Consulting Engineer, Los Angeles

(Reprint from "Western Construction News," February 25, 1926)

The City of San Diego proposes the construction of a 32-in. pipe-line 25 miles long, for a domestic water supply. As an aid in the preparation of the specifications, the following tests of lock-bar steel pipe were made at the Pacific Coast Steel Co. laboratory in South San Francisco, in the presence of Fred A. Rhodes, City Manager of San Diego, T. A. Mills, Assistant Engineer, and the writer as Consulting Engineer, on January 29, 1926.

A section of 42-in. lock-bar pipe made of ¼-in. flange steel for the City of Portland was obtained for the purpose of this test, primarily to determine the joint efficiency of the pipe.

This class of pipe originated in Australia where it was first used in the Coolgardie pipe-line 350 miles long and 30 in. diameter. It has since been used in numerous Eastern cities and in Portland, Seattle and Tacoma. The equipment for its manufacture is of a heavy and elaborate nature and is now installed at the Willamette Steel Co.'s plant at Portland. This equipment has lately been purchased by the Western Pipe & Steel Co. for installation at its San Francisco plant. The illustrations show the nature of the lock bar. This lock bar is cold rolled on the upset edges of the plates with a pressure of 350 tons per lineal foot. The manufacturers claim a joint efficiency of 100% for plates 3/16 in. to 7/16 in. thick. Thinner plates cannot be upset and bars for plates thicker than 7/16 in. are said to give joint efficiencies of less than 100%.



Tension Test of Lock-Bar Steel Pipe

Tests of Lock-Bar Pipe Joints

At Laboratory of Pacific Coast Steel Co., South San Francisco, January 29, 1926.

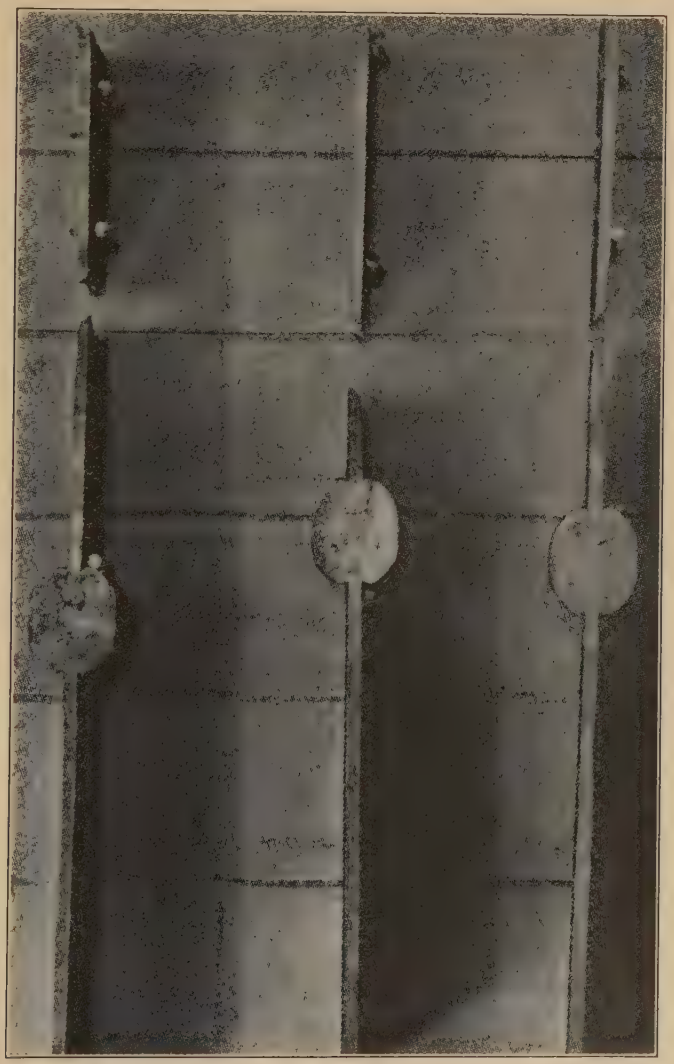
Number of Test	Class of Pipe	Section		Area Section Sq. in.	Reading		Per sq. in.		Joint Eff. %	Remarks
		Width In.	Thickness In.		Elastic Limit	Tensile	Elastic	Tensile		
a	Lock bar	1.9	¼	0.475	18,000	29,950	38,000	63,100	115+	Flange steel
b	"	2.004	¼	0.501	18,200	29,980	36,320	59,850	109+	"
7	"	2.0	¼	0.5	.....	30,030	.....	60,060	110+	"
9	"	2.0	¼	0.5	17,320	29,980	34,640	59,960	109+	"
9–a	"	2.0	¼	0.5	.....	31,030	.....	62,060	113+	"
12	"	2.0	¼	0.5	18,000	29,960	36,000	59,920	109+	"

Sections were cut from the Portland pipe, 2 in. wide and 16 in. long, the lock bar being in the center. The table given below shows the results of all the breaking tests, although tests "a" and "b" were not witnessed by the writer. In no instance did the lock bar yield or break. "Joint efficiencies" given are determined by dividing the ultimate pull by 55,000 lb., which is the nominal strength per square inch of the steel plate. In reality the joint efficiency is some unknown percentage above that given.

The following notes relate to these tests:

No. 7. The sample was first put in a vise, which was clamped ½ in. below the bar and the top bent 122 deg. as shown in the illustration. No opening occurred in the joint. The sample was next bent back and down, 122 deg., in the reverse direction. The sample was then straightened and pulled, the plate breaking at 60,000 lb. per sq. in., and the lock bar being intact. Although the lock bar did not yield from either the bending or the tension tests, apparently the cross-section of the plate decreased slightly or enough to show some hair line marks at the sides of the bar joint.

In Test No. 9 the plate was not at first bent in the vise as in the case of Test No. 7. Under tension the plate broke with a pull equivalent to 59,960 lb. per sq. in., the break occurring 4 or 5 in. from the bar. The sample was then again put in the pulling machine, the grip being taken as close as possible to the lock bar, with the result shown in Test No. 9-a, the steel plate breaking with the tension equivalent to 62,060 lb. per square inch.



Tension Test of Lock-Bar Steel Pipe

Test No. 7 of Lock-Bar Steel Pipe

Sample No. 12 was put in the pulling machine and gripped within 2 in. of the bar, which was as close a hold as could be obtained. The plate then broke with a pull equivalent to 59,920 lb. per sq. in. Sample No. 12 was also tested for bending as in the case of Sample No. 7. The lock bar was not opened or broken in any of these tests.

It cannot be stated what the joint efficiency was, except that in each one of these instances it was in excess of 109% of the theoretical tensile strength of the plate itself. These steel plates were Class A steel with a theoretical strength of 55,000 lb. per sq. in. The joint efficiencies in the tables are determined by dividing by 55,000 lb., the ultimate strength as shown by the test, the theoretical strength of the metal. This joint efficiency therefore is the amount shown plus some unknown percentage. Therefore these percentages are indicated with the plus sign following.

None of the breaks of the lock-bar pipe occurred at the joints.

After making the bending and tensile tests given below, a ring of the 40-in. Portland lock-bar pipe, 4-in. wide, was put under a press with the lock bars at the quarter points. The sample was pressed flat and then released without any indication of failure either in the plate or in the bar.

The following data relative to tests of lock-bar pipe were obtained from the Pittsburgh Testing Laboratories. These tests were made at the request of the engineer for the Omaha, Nebraska, Water District, who was present while the tests were being made.

PITTSBURGH TESTING LABORATORY

Inspecting and Consulting Engineers and Chemists,
Pittsburgh, Pa.

January 28, 1926

Report of Tensile Test of Lock-Bar Pipe Joint,
Made for Riter Conley Company.
Oliver Building, Pittsburgh, Pa.

Description	Original area sq. ft.	Yield point lb.	Maximum lead lb.	Yield point lb. per sq. in.	Tensile strength lb. per sq. in.	Fracture
Tests made Sept. 11, 1925 Laboratory No. 55734						
No. 1	750	27500	44160	36660	58880	
No. 2	750	27100	44950	36130	59930	
No. 3	750	27150	44300	36200	59060	
Tests made Oct. 12, 1925 Laboratory No. 55915						
No. 1	8000	27450	43680	34310	54600	Broke in material outside of joint
No. 2	8028	27530	44370	34290	55270	
No. 3	8040	28330	44780	35240	55700	
No. 4	8008	27650	44050	34220	54520	
No. 5	8040	27130	44680	33740	56820	
No. 6	810	27000	44950	33330	55490	

Note: These test bars were cut from finished pipe sections. You will note the joints in all cases were intact. There was no slip of the joint at the yield point of the metal and the test bars broke in the original plate without forcing the joint.

Pittsburgh Testing Laboratory,
J. W. Reifsnyder,
Engineer of Tests.

Flow of Water in Steel Pipes

The City of Portland has laid three main water supply lines from Bull Run to the city. Measurements were made to determine the value of "*c*", in the Williams & Hazen formula for the flow of water in pipes, in one of these lines which has recently been laid. This pipe consists of 48,967 ft. of 58-in. lock-bar pipe and 1468 ft. of 58-in. diameter triple riveted, double butt-strap pipe, this riveted pipe being in Section "D" referred to below. The volume of flow was the average of the

readings of two venturi meters (Builders Iron Foundry) and a weir at a reservoir. The rate of flow was 75,000,000 gal. for 24 hours.

Section "B" had a length of 8702.35 ft. with a grade of 1.5 in a thousand. The value of "*c*" in the Hazen & Williams formula in this section was determined as 141.

Section "C" had a length of 7918.65 ft. with a slope of 1.68 ft. per thousand and a value of "*c*" of 132.

Section "D" which contained the 1,468 ft. of riveted pipe was 30,964.4 ft. long with a slope of 1.59 ft. per thousand and with a value of "*c*" of 136. The total length of the line, including a section of 2850 ft. which contained the venturi meter not included above, was 50,435.4 ft. with an average slope of 1.64 and an average value of "*c*" in the Hazen & Williams formula of 134, which is equivalent to "*n*"=0.0113 in the Kutter formula.

The angles in these pipe-lines are made of riveted steel pipe. The average of these angles per thousand feet in Section "B" was 47° 43′, in Section "C," 75° 22′, and in Section "D," 46° 47′.

These tests were made on April 10, 1925, by B. T. Morrow, Engineer of the Bureau of Water Works of Portland, Oregon. The lock-bar pipe was new. The coefficient of 134 is comparable to the coefficient of 36-in. new cast-iron pipe which is stated by Williams & Hazen to have a value of "*c*" of 130.

Headworks
Bull Run Conduits

Portland, Ore., is dependent entirely upon Lock-Bar Steel Pipe for its water supply.

Here's the record of Portland's installations.

CONDUIT No. 2

1909—9,600 ft. of 48 and 24 in. pipe.

1910—128,000 ft. of 52 and 44 in. pipe.

CONDUIT No. 3

1924—132,000 ft. of 58 and 50 in. pipe.

1926—22,000 ft. of 40 in. pipe.

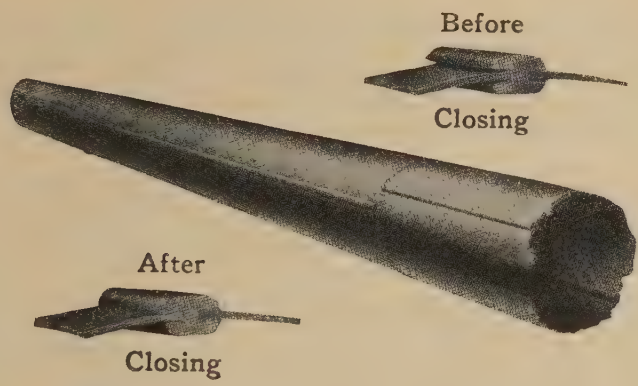
100% Lock-Bar Pipe

Portland, Oregon Bull Run Conduit No. 3. South Side Road—Looking Down-stream
58" x 5/16" Lock-Bar Pipe

Portland, Oregon, 1925. Bull Run Conduit No. 3. [redacted] South Side Rock Excavation—Looking Up-stream.
58" Diameter Lock-Bar Pipe

Portland, Oregon. Pipe Bridge for Conduit No. 3.

Portland, Oregon. Bull Run Conduit No. 3. Sandy River Hill.
58" Diameter Lock-Bar Pipe



LOCK-BAR STEEL PIPE

Prominent Water Works Engineers consider the twenty-five years of continuous service of Lock-Bar Steel Pipe under favorable and unfavorable conditions assures the maximum of safety and efficient long life.

Lock-Bar Steel Pipe with the 100% Lock-Bar Joint and smooth interior has satisfactorily proved its dependability and lasting qualities.

Manufactured in 30-ft. lengths, except where shorter lengths are required to meet angles or curves in grade and alignment, with riveted taper circumferential field joints, it is easily handled and rapidly installed.

EAST JERSEY PIPE COMPANY

7 Dey Street, New York City

LOCK-BAR

Before Closing

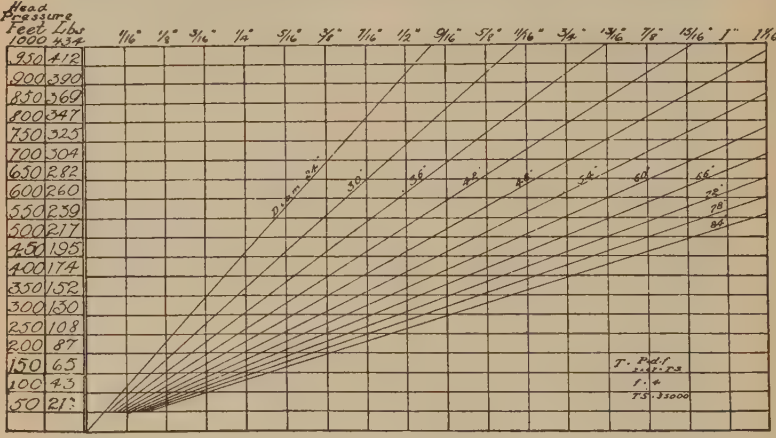
STRONG AS THE PLATE ITSELF

Strength of Joint

The lock-bar joint is 100% efficient or equal to the strength of the plate itself. It is therefore possible to use in many instances lock-bar pipe of a thickness of plate $\frac{1}{8}$ or $\frac{1}{16}$ inch less than the thickness required in riveted or welded pipe where the joint efficiency is less than the strength of the plate.

Hydraulic Test on 42-inch Pipe

On Jan. 2, 1909, official tests were conducted by the Robert W. Hunt Co. for the City of Springfield, Mass., on a 42-inch



Double Riveted Pipe

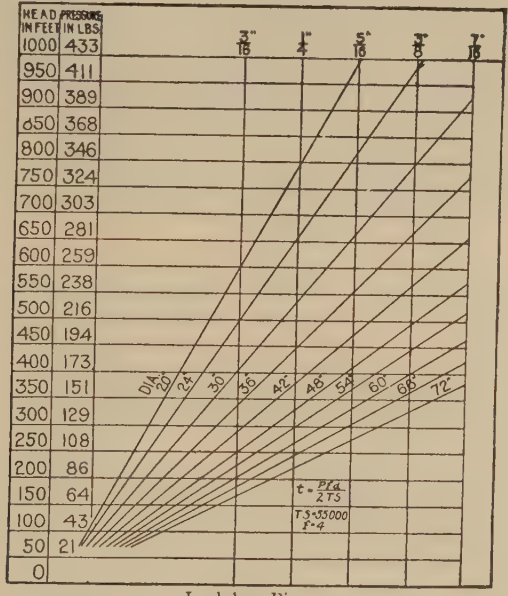
diameter, $\frac{7}{16}$-inch plate lock-bar pipe under pressure of 1,050 pounds per square inch. The metal of the plate was stretched over 4 inches in circumference without injury or leakage along the lock-bar joints. Higher pressure was not possible because of blowing out riveted pads at gauge and inlet. At this pressure, the pipe was actually exceeding by 765 pounds per square inch its normal working pressure.

Superiority of Lock-Bar Pipe

The usage of steel pipe increases in direct proportion to the working pressures and the necessity for uninterrupted

service. An increasing tendency toward the use of steel pipe on distribution systems through city streets has been noticeable in recent years. On supply mains, gas lines, hydro-electric installations, etc., where such characteristics as dependability, flexibility and shock-absorbing qualities are paramount, steel pipe is almost exclusively used.

From the severity of the specifications of materials and construction, and the complete and modern methods of fabrication of lock-bar pipe, it is evident that in no pipe works is greater precaution taken to safeguard the interests of the purchaser.

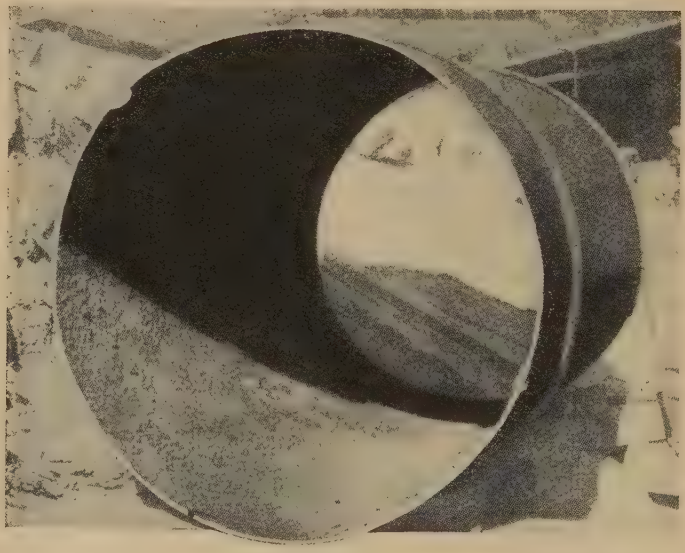


Lock-bar Pipe

Comparative Charts (see preceding page) Showing Safe Working Pressures for Riveted and Lock-Bar Pipes Based upon Formula $T = \frac{PFD}{2TS}$; $T.S.$ = 55,000 Lbs.; F = Factor of Safety 4.

Sizes

Lock-bar pipe is made in diameters from 20 to 74 inches and upwards, and thicknesses of plate from 3/16 to 1/2 inch, inclusive.



After 39 Years—still good for 39 more!

In the year 1891, about fourteen years prior to the introduction in this country of *Lock-Bar Steel Pipe*, the City of Newark, New Jersey, laid 142,000 feet of 48-inch and 36-inch Diameter Steel Pipe for the conveyance of their main water supply from the Pequannock Watershed and this line has been in continuous operation since its installation.

It became necessary in October, 1925, to cut an 8-foot section from this line in connection with the placing of a valve near Macopin Intake, at which point the original thickness of the plate was ¼ inch. The pipe was found to be in almost perfect condition after thirty-five years of constant service, thus warranting the prediction that the line is good for at least another thirty-five years.

East Jersey Pipe Co., 7 Dey Street, New York City

LOCK-BAR

STRONG AS THE Before Closing PLATE ITSELF

Life of Steel Pipe

Steel pipe is not an experiment. Several lines have been in service for over 35 years, which are today in excellent condition. It is impossible to go back more than 35 or 40 years for the reason that steel plates were not obtainable in sufficient quantities prior to that time, and therefore but little steel pipe was made earlier. The oldest line was of "Tank quality steel" with chemical contents which frequently ran high in ingredients favorable to corrosion. "Flange quality plate" is now being specified, and insures the use of highly refined plate calculated to give the longest possible length of life. A distinct advantage of steel pipe, as it is manufactured today, lies in the fact that marked progress has been made in pipe coating which materially increases the longevity of steel pipe lines.

ELECTROLYSIS is a form of corrosion due to electric currents which have strayed, generally from the return circuits of electric railways. Where these currents jump around an insulating joint or go back by some other path to the generators furnishing the currents, corrosion by electrolysis may occur.—(Manual of The American Water Works Association, 1925.)

Destruction of a pipe by electrolysis occurs in two ways: (1) By a current collected by the pipe, following it for a distance and then leaving it in moist soil, the electrolysis occurring at the point where the current leaves the pipe. (2) By the flow of electricity in the pipe, a part of which leaves the pipe at lead joints or other points of extra resistance, coming back into the next length of pipe. These two kinds of electrolysis, while having the same effect on the pipe, are to be sharply distinguished. Electrolysis of the first kind may be corrected in great measure by connecting the pipe system with the negative poles of the dynamos at all power stations. This has the effect of taking the return current out of the pipes directly through a copper wire and avoiding the necessity of currents leaving the pipe in moist ground on the return journey. This method of treating the electrolysis question was proposed in the early days of electrolysis and used to a considerable extent. The principal objection to it is that it produces electrolysis of the second kind. This system is openly followed in some works, and is actually followed by unknown and indirect connections in others.

In cast-iron pipe lines the lead joint is a point of high resistance. The temperature of the melted lead is not sufficient to burn off the tar coating, and actual metallic connection is not made in all cases. The electric current goes through the soil around the joint in sufficient quantity to produce electrolysis on one side of the joint. This takes place in wet soil only. Dry soil is a non-conductor. When electricity makes a passage it goes through the water contained in the pores of the soil, and not through the soil particles. Water is a non-conductor, but it becomes a conductor when mineral substances are dissolved in it.

Electrolysis of the interior of pipes is extremely rare, because the water used for public water supply is not sufficiently mineralized to act as a conductor. If the water in the soil outside the pipe were equally pure from an electrolytic standpoint there would presumably be little trouble from this kind of electrolysis.

Electrolysis occurs because the ground water contains mineral matter and salts which increase its conductivity. The mineral matters in ground water may result from many sources, among them: (1) From cesspools and similar sources, which are known to increase the chlorine contents of ground water to from 10 to 100 times the natural amounts, in villages and cities, and to less extent in rural districts, (2) Sea water brought by the rain, this being a matter of importance only when pipes are not very far from the ocean, (3) Solution of mineral matters from the soil.

Insulation joints are joints made of some non-conducting material to prevent the flow of electricity in pipes. Such joints have been made by driving wooden wedges between the spigot and bell of the cast-iron pipe in place of the lead. To be effective they must be repeated at short intervals, as the electric current will jump a number of such joints, passing through the surrounding moist soil and causing electrolysis at each of them.

Electrolysis of Steel Pipe. The riveted joints of steel pipe are almost perfect conductors of electricity. There is no evidence that a current flowing in a steel pipe injures it in any way as long as it does not leave the pipe. An electric current

flowing in steel pipe and leaving it results in electrolysis at the point where it leaves the pipe.

Corrosion. Corrosion is a process or combination of processes by which metals wear away. Two casual factors are requisite to corrosion; moisture or water, or air and oxygen. In the absence of moisture metals do not corrode; in the absence of oxygen they are attacked but slightly. Corrosion more than any other factor or combination of factors, determines the efficient life of water pipe. In metal pipes corrosion disintegrates the metal and reduces the wall thickness.

Corrosion is caused by electro-chemical action; chemical because corrosion is due to reactions of the metal with different elements or compounds in the water; and electrical because these reactions require a concurrent interchange of electrical charges.—(Manual of the American Water Works Association.)

LOCK-BAR Steel Pipe can be protected by coating or wrapping so as to render it immune from corrosion, incrustation and electrolytic action, thus insuring increased length of service.

Numberless discussions have taken place as to the relative life of steel, wrought-iron and cast-iron pipe, in-so-far as corrosion affects durability. One of the strongest arguments in favor of steel pipe over wrought-iron, in this respect, which has come to our notice within recent years, aside from the actual testimony of installations, is that presented by one of the best known seamless tube and small pipe manufacturers in the country, in their abandonment in 1909 of charcoal and puddled iron for steel tubes. We quote from this testimony as follows: "The use of steel for welded pipe was made possible, in the first place, through the manufacture * * * of a special grade of low carbon steel. * * * Steel pipe has in later years superseded wrought-iron pipe by proving its superiority in strength, ductility, and finally, as made under modern processes, by its superior durability.

"As manufacturers of both wrought-iron and steel pipe for many years, we have had a special interest in this question of durability, about which there has been so much debate, and with our dual interest have had exceptional opportunities to make comparison of these materials under all manner of service. Moreover, we have frequently shipped a wrought-iron

coupling on steel pipe, so that in case of any external corrosion a comparison of the two materials could be readily made under the same conditions. As a result of an extended study of this question in the laboratory and in the field, and with the experience of many large consumers of pipe, who have made careful observations from cases where both iron and steel pipe were used under the same conditions, there was no further room for doubt as to the advantage of steel pipe, * * * in respect to its resistance to corrosion, particularly as to pitting. * * *."

Cause of Corrosion. There is considerable difference of opinion on this particular phase of the subject but nevertheless the following is given as a condensed survey of a few underlying facts which have been established by experiment.

We quote from a recent authority on the subject:

"It is claimed by some who have studied the problem that corrosion is due to 'differences' of electrolytic potential between two adjacent places on the surface of the metal, resulting in pitting. This difference may be due to lack of homogeneity in the metal, but, it is believed, more often is caused by foreign matter electro-negative to iron, attached to the surface, such as mill scale, carbon or rust itself. It has been clearly established that corrosion consists of two main reactions, namely, the solution of a small part of the iron in water, and the subsequent oxidation of the ferrous iron in solution to ferric hydroxide, which is then precipitated out as "rust.' The amount of the corrosion is still further increased by the combination of free oxygen with the hydrogen, which was deposited on the surface of the metal when iron went into solution. This cycle of reactions is repeated, and the 'rust' continues to accumulate so long as both water and air are present. Other agencies may accelerate the process of corrosion, but in the absence of either one of these elements no corrosion can take place. Steel will remain clean and bright for an indefinite period in dry air, and also in water that is free from air. Hence the necessity to see to it that * * * iron and steel * * * are protected by impervious and durable coatings."

The late Prof. F. L. Kortright says:

"The rusting of iron or steel is caused by the combined action of water (condensed on the metal), carbon dioxide (or

some other volatile acid), and oxygen, and the presence of certain salts increases the rapidity of action. The effect of the substances seems to be, first, the formation of ferrous carbonate, then ferrous bicarbonate and this is broken down into magnetic oxide of iron (giving off the carbon dioxide which acts on more iron to form ferrous carbonate), and the magnetic oxide is finally oxidized to hydrated ferric oxide which is the ordinary condition in which rust exists."

Steel vs. Cast-Iron Pipes. The Coolgardie pipe line which was a 30-in. steel pipe main installed in Coolgardie, Australia, in 1900, is frequently referred to by certain interests as an example of a failure of steel pipe. In the evidence of the various experts appointed by the Commission to investigate the troubles attending the Coolgardie pipe line many interesting facts were disclosed. The water supply itself was found to contain 26 parts of sodium cloride and 5 parts of magnesium cloride per 100,000. The report states:

"It is to be expected that such a water would possess more than usual corrosive action upon iron or steel."

With regard to the external corrosion, the report states:

"The sandy soil along this pipe line is so impregnated with salt that in many places it absolutely glistens, in which case it is hardly surprising that external corrosion set in. The main is seriously corroded over a portion of its length which had been coated with a special solution applied at a low temperature; so low, in fact, that under the burning sun of West Australia it was found that the coating ran off the pipes before they were laid. For this reason this particular coating was abandoned and a harder coating subsequently used. Unfortunately, the benefit of this hard coating was largely neutralized as some of the pipes were exposed to the sun for two years before they were laid. On inspection it was found that wherever the pipe line was sufficiently coated, despite these corrosive surroundings, was practically in as good a state of preservation as when laid. Had the pipes been laid above ground as recommended by the Commission, the external corrosion as caused by the soluble salts contained in the soil would have been entirely done away with."

Showing Effect of Electrolysis on Cast Iron Pipe—Specimen No. 2.

Extract from "Civil Engineering," April, 1912:

"Evidence of any local failure of either cast-iron or steel pipes is of little value when comparing the two metals unless one has evidence of the behaviour of both under similar conditions. Fortunately, in the case of the West Australia Pipes (Coolgardie) there is ample evidence on both sides. In this district a 12-in. cast-iron main was laid in 1890. This gave considerable trouble, so that when an increased supply was required in 1897, a 21-in steel main was laid, and this has proved highly satisfactory. The Perth supply (delivered by a 12-in. cast-iron and a 21-in. steel main) contains about 12 grains per gallon of these corrosive compounds. Eight years ago the cast-iron main was so corroded that scraping from end to end was necessary, and five years later this process had to be repeated.

"The illustration, which was taken at random, shows the appearance of one of these pipes after five years' corrosion. The nodules of rust were found to be from 2 in. to 3 in. thick, and covered the entire inner surface of the pipe. On removal, the metal surface of the pipe appeared to be unaffected. On investigation, however, it was found that it could be cut into with a knife, and a soft black mass 3/16-in. thick was removed. Under this the true metallic surface was found to be extensively and irregularly corroded.

"A section of the 21-in. steel main was removed for examination after eleven years' use. The coating of this pipe was in good order, being dark and lustrous, and showed very little evidence of decay. The surface of the coating was covered with a very thin film of brown earthy sediment, which, however, was not sufficiently thick to hide the coating.

"In comparing cast-iron and steel pipes it is desirable to further study Australian experience. The facts are that, while under exceptionally unfavorable conditions the Coolgardie main has given some trouble, the local experts know by bitter experience that cast-iron would have given much more. All the other leading centers throughout Australasia—Melbourne, Sydney, Adelaide, Perth, Brisbane, Auckland, Wellington, and a number of others—are supplied with steel water mains which, one and all, have proved unqualified successes. The original Melbourne wrought water mains, 58 miles long and varying in

diameter from 32 in. to 53 in., were laid in 1884. According to recent advice from the Inspector-General of Works in Melbourne, these mains are in as good preservation as when laid. The same condition prevails in other smaller mains installed there since. One—a 24-in. main—laid in 1887 is particularly interesting in that it affords a direct comparison with cast-iron."

The engineer wrote, with regard to this main:

" 'Some alterations in this main necessitated cutting out a length, including a 12-in. cast-iron branch nipple. This I found to be an advantage, as it afforded me a welcome opportunity of examining the plates in several places. Inside the pipe is now as if it had just come out of the (tube) works, so perfect and japan-like is the coating, and, making allowance for the adhering clay, the same may be said of the outside. This is the more remarkable from the fact that, in an equal period, a cast-iron pipe of equal diameter would have lost at least 1 in., and more probably 2 in., of section from corrosion. The cast-iron branch which had been connected to this wrought-iron pipe, with its valve, were heavily covered with material adhering to the inner surface in the form of nodules, and consisting of oxide of iron and earthy matter attracted to it. This deposit or incrustation is peculiar to all cast-iron pipes, large and small, in the Melbourne water-supply system. Its rate of growth is equal to the complete filling up of a 4-in. pipe in from 15 to 18 years.'

"Profiting by the success of steel pipes in Australasia, other countries have followed suit. Eighteen years ago Durban (South Africa) laid an 18-in. water-supply main of steel which proved so successful that two years ago they again ordered another large steel main. Monte Video, after experience of cast-iron, duplicated their existing main with one of steel 30 in. in diameter and 30 miles long. Fifteen years ago Bradford (Yorkshire) laid two 36-in. water-supply mains which have proved an unqualified success. Some years ago the Leeds Municipal authorities, having in view the experience of Bradford, laid 24 miles of 33-in. steel pipes for a water supply. In Leeds neighborhood there are well preserved samples of wrought-iron pipes which have been in the ground from fifty to sixty years. Other towns in Great Britain which have laid steel

mains during recent years are Manchester, Swansea, Cardiff and many smaller towns. All the leading centres of population throughout South Africa have adopted steel water mains, some of which have been in successful operation for over twenty years.

"Probably the best evidence of the successful application of steel pipes is the rapidly increasing demand for them in all parts of the world in recent years."

Relative Corrosion of Wrought Iron and Steel. (H. M. Howe, Proc. A. S. T. M., 1906.)

"On one hand we have the very general opinion that steel corrodes very much faster than wrought-iron, an opinion held so widely and so strongly that it cannot be ignored. On the other hand we have the results of direct experiments by a great many observers, in different countries and under widely differing conditions; and these results tend to show that there is no very great difference between the corrosion of steel and wrought-iron. Under certain conditions steel seems to rust a little faster than wrought-iron, and under others wrought-iron seems to rust a little faster than steel. Taking the tests in unconfined sea water as a whole wrought-iron does constantly a little better than steel, and its advantage seems to be still greater in the case of boiling sea water. In the few tests in alkaline water wrought-iron seems to have the advantage over steel, whereas in acidulated water steel seems to rust more slowly than wrought-iron.

"Steel which in the first few months may rust faster than wrought-iron may, on greatly prolonging the experiments, or pushing them to destruction, actually rust more slowly, and vice versa.

"Carelessly made steel, containing blowholes, may rust faster than wrought-iron, yet carefully made steel, free from blowholes, may rust more slowly. Any difference between the two may be due not to the inherent and intrinsic nature of the material, but to defects to which it is subject if carelessly made. Care in manufacture, and special steps to lessen the tendency to rust, might well make steel less corrodible than wrought-iron, even if steel carelessly made should really prove more corrodible than wrought-iron."

For extensive discussions on this subject see Trans. Am. Soc. C. E., Trans. A. I. M. E., Proc. A. S. T. M., and Bulletins of National Tube Co.

Experiments made at the Riverside Iron Works, Wheeling, W. Va., on the comparative liability to rust of iron and soft Bessemer steel: A piece of iron plate and a similar piece of steel, both clean and bright, were placed in a mixture of yellow loam and sand, with which had been thoroughly incorporated some carbonate of soda, nitrate of soda, ammonium chloride, and chloride of magnesium. The earth as prepared was kept moist. At the end of 33 days the pieces of metal were taken out, cleaned, and weighed, when the iron was found to have lost 0.84% of its weight and the steel 0.72%. The pieces were replaced and after 28 days weighed again, when the iron was found to have lost 2.06% of its original weight and the steel 1.79%. (Eng'g, June 26, 1891.)

Life of Steel Lines. The Pequannock lines of the City of Newark have been in continuous service for 37 years without requiring major repairs. Similarly, the 30-year old Boonton-Jersey City steel line, and the 31-year old Little Falls-Belleville line. The 1925 report of the North Jersey District Water Supply Commission, page 74, records that

"Several recent inspections of the interior of the pipes have shown that they are in a satisfactory condition, considering their long use, and may reasonably be expected to continue in service for many years."

The probable life of steel pipe still is in debate. When is a pipe worn out (unusable)? Mr. J. Waldo Smith, in 1920, gave its life as more than 50 years. Mr. T. A. Leisen, 100 years, or more. Properly protected on the outside with insulating wrappings, electrolysis will be guarded against as well as corrosion. On the inside, periodic brushing, and recoating in places if necessary, will keep the pipe clean and otherwise in first class condition. Pipe so laid and cared for ought to have a life of at least 100 years, and more.

As early as 1900 Mr. John R. Freeman, Past President American Society of Civil Engineers, wrote:

"The reliability, utility and economy under certain conditions, of properly constructed large steel pipe conduits are now thoroughly established. * * *

"Lest the large diameter of certain of the steel conduit lines proposed in parts of this estimate might excite apprehension among those not familiar with what has heretofore been done with large steel and iron pipes in water-power developments, it may not be amiss to mention that pipes of the same diameter as the largest which enters any of these estimates (9 feet), but of poorer metal, have been in use for fifty years leading to the water-wheels of certain of the mills at Lowell and Lawrence, and the original pipes are still in good condition. It is true that these old pipes were of shorter length and subjected to much less pressure than the proposed conduits, but as an offset, it is to be noted that they were built of poor metal and less efficiently protected against corrosion. At Holyoke and at least two other large water-powers, pipes of this same kind up to 12 feet diameter, are in use today. Many steel pipes of 6 and 8 feet diameter have been laid in lengths of 800 or 1,000 feet, some exposed to the weather and without expansion joints, and some deeply buried. To the water-power engineer it is a matter of very frequent practice to bury in the ground beneath a large factory a conduit of this size for a feeder to its water-wheels. The mill-yard experience is ample to show that a pipe up to nine and even twelve feet diameter by ⅜-inch without any stiffening ribs or special support, need not be injured by the back-filling necessary, and will take care of its own temperature strain. * * *

"I believe that if built under proper supervision a 9-foot steel pipe may be regarded as a safer structure than the 48-inch cast-iron pipes commonly used. * * *

"The experience for eight years, summer and winter, with the East Jersey conduit 21 miles long, 4-feet diameter of similar metal, and with many riveted wrought-iron pipes in California, as well as with certain large water-wheel feeders already mentioned, shows that these large pipes can be safely left to take care of their own temperature strains without expansion joints, if firmly anchored to ample masonry at their ends.

"In considering the effect of rust after long service, it is to be remembered that experience shows that very little rust

occurs within the joint between the plates. The joint is the weakest part of a riveted conduit, because of the rivet holes cutting out 30 per cent. of the strength that opposes bursting; but as the conduit becomes weakened as it grows old, through the thinning of its metal by rust, the plates at the joint become weakened only about half as fast as the main body of the plate, because rust only attacks them on one side. I have had recent occasion to make careful observation on some unprotected and badly rusted penstocks that had been more than forty years in use. Many instances of cutting open at the joint showed very little loss.

"In designing the thickness of plates and the strength of joint required to withstand the various water pressures, 1/16-inch has been added to the computed thickness to provide against the weakening by rust. If corrosion were to go on with equal rapidity inside and out, then 1/8-inch could be removed from the plate as a whole, before the factor of safety of 2½ would begin to be encroached upon; in other words, a ½-inch plate could be thinned down to 3/8-inch.

From observation on various penstocks from twenty-five to fifty years old, it appears reasonable to assume that more than fifty years would elapse before this condition of encroaching upon the factor of safety against bursting, or before the reduction in bursting strength of body of plate would be brought by corrosion below the original estimated strength at the riveted joint."

Water Works Practice, Manual of American Water Works Association, 1925, page 290, states that the use of steel pipe as a water carrying medium dates back approximately forty-five years. Metcalf and Eddy, in their book "Design of Sewers," 1914, however, state that they personally examined steel pipe which had been in service in the system of the Spring Valley Water Company (California), for some 47 years, and found the coating still plastic and practically unbroken. The carrying capacity was well maintained, being within 10 per cent. of its original amount as indicated by certain friction loss tests. They concluded that steel pipe can be expected to carry its pressure for a period of 60 to 75 years.

An instructive testimonial is furnished by Charles A. Finley, under date of March 26, 1919, when he was Managing Engineer, Department of Public Works, Pittsburgh, Pa., as follows:

"In March, 1914, the City had occasion to make three (3) 24″ pressure connections with the 60″ steel pipe line which was laid about 1895, from Montrose Pumping Station to the old Troy Hill Reservoir, a distance of about ten miles. Three (3) 24″ cuts were made in the side of the steel pipe and the condition of the pipe carefully noted. The original thickness of the plate is recorded as one-half inch. The cuts, upon careful measurement, still show the full original thickness. We were unable to demonstrate any appreciable deterioration in the pipe during the twenty years that it was in service.

"In 1918 it again became necessary to cut the same line at the Filtration Plant, this work being done with an acetylene torch. The pipe was found to be in good condition and showed no appreciable loss of metal due to the twenty-four years of service. The condition in which this pipe was found, would indicate that it was entitled to credit for much longer service than it has been customary to grant to this type of steel.

"About the time this pipe was laid, if I remember correctly, it was very strongly contended that this pipe would only be good for about thirty years. It has now been in service twenty-four years and the condition of the pipe indicates that its possible life was under-estimated."

Mr. F. W. Cappelen, under date of December 29, 1911, furnishes the following information:

"As City Engineer of Minneapolis I had occasion, in 1897, to build two large pipe lines for the City.

"After a thorough investigation I was convinced that steel pipe would in every way satisfy the existing conditions, but to please the advocates of cast-iron, bids were received for both steel and cast-iron pipes. The steel was fifty inches in diameter, the cast-iron pipe forty-eight inches; maximum pressure 125 pounds per square inch; total length of pipe 33,000 feet, of which 1,500 feet were submerged, crossing the Mississippi River.

Lowest cast-iron bid.....	$477,500.00
Lowest steel pipe bid.....	343,726.00

"On June 18, 1897, contract for steel pipe was awarded to the T. A. Gillespie Company of Pittsburgh and the entire job

finished November 9th of the same year—a most remarkable record—and I cannot too highly recommend the T. A. Gillespie Company for doing splendid work in every respect.

"I have several times had occasion to examine this pipe line personally, both inside and outside, and found the coating just as good as new.

"The coating used was the so-called Rubber Asphaltum, manufactured by the Assyrian Asphalt Company of Chicago, now the American Asphaltum & Rubber Company of Chicago. I determined the use of this particular coating after exhaustive tests and experiments.*

"We have never had a leak on the entire line since the water was turned on, fourteen years ago. We have, on the other hand, a constant trouble with submerged cast iron line of which we have three across the Mississippi.

"I have also been connected with the 6 to 8 miles long 42-inch steel pipe lines for Seattle, Washington, Water Works, with entirely satisfactory results. I have also put in steel intakes on very exposed places on Lake Superior. The steel mains stood the racket, but the cast-iron specials in connection with the work did not.

"Taking the saving and everything else into consideration, I recommend large steel pipe instead of cast iron pipe. Of course with the proviso that the steel pipe is properly designed, manufactured and laid."

In 1919 Mr. John Swan, as Director of the Department of Public Works of Pittsburgh, Pa., wrote us respecting a 60-inch steel pipe line 24 years old, as follows:

"Relative to your inquiry as to our experience with steel pipe, beg to inform you that the former City of Allegheny, now a part of the City of Pittsburgh, laid a 60-inch steel line from the City to Montrose Pumping Station, a distance of about ten miles, in 1895. In 1918 we had occasion to lift about 40 ft. of this line to put in some gates and connections. We found that upon moving two sections of this 60-inch line, it was practically in perfect condition. Tests which were made for corrosion and weight showed that the steel had lost comparatively nothing in

*No longer used by our company.

this length of time. From all appearances, I would judge that this line was good for at least 25 years more."

Some Examples of Steel Pipe Longevity. Theodore A. Leisen, in his paper "Steel Pipe for Large Water Mains," presented before the Philadelphia Convention, American Water Works Convention, May 19, 1922, (pp. 393-399), said:

"But what is the assumed life of steel pipe? The use of steel in the manufacture of water mains being a development of comparatively recent years, there are no data extant to determine definitely the actual *average* life of such pipe under ordinary conditions of service, but the experience of the last twenty or thirty years has demonstrated that it may be depended on for a much longer period than was credited to it by most engineers in the past. An approximate idea of the probable useful life of steel pipe may be obtained only by accepting as a basis the established facts regarding existing lines of riveted pipe that have been in continuous service for periods of fifteen to thirty years, and by computing the total life by proportioning the percentage of deterioration, if any, evidenced during its past period of service, to the total percentage of deterioration which would make the pipe unfit for further service.

"Following this method of procedure and using rational judgment in its application, it may be shown that in some instances steel pipe may attain a useful life of one hundred years. The principle involved in the suggested method would in reality be on the side of conservatism, as apparently the first rust scale forms more rapidly than successive ones, and if the first ten years showed a given loss by corrosion, it is doubtful whether the second decade would show a proportional loss.

"As a basis for the application of this method for computing the assumed useful life of the steel plate, a few concrete examples taken from records at hand are submitted:

"1. A 50-inch diameter riveted pipe was installed at Pittsburgh, Pa., fifty-one years ago, and is still in service, but the deterioration suffered could not be ascertained.

"2. A riveted steel main, 50 inches diameter, laid in Allegheny, Pa., twenty-seven years ago, is still in service, and an examination of a section of plate cut therefrom shows no appreciable deterioration.

"3. A section of 62-inch diameter riveted steel pipe recently removed from a connection to the settling basin of Detroit Water Works, and which has been in service in that position for forty-five years, but which apparently had been used for some other purpose prior to its installation and therefore may be several years older. This pipe was made of $\frac{3}{8}$-inch plate. The exterior surface of the plate was in excellent condition, the original paint still remaining in places, but the interior showed some corrosion and pitting, the deepest pits being about $\frac{1}{32}$-inch or less than ten per cent. of the thickness of the plate. Assuming that the plate could be pitted to 50 per cent. of its thickness before its efficiency would be destroyed—and this is a conservative assumption—then this pipe would have a useful life of five times forty-five or over two hundred years.

"4. Several miles of 48-inch diameter steel pipe laid in New Jersey, near Newark, which have been in service for twenty-seven years, show little or no indication of deterioration, although portions of these lines are subject to occasional contact with salt water.

"5. About four miles of 43-inch and 48-inch 'Lock-Bar' steel mains laid in Wilmington, Delaware, seventeen years ago, apparently are in as good condition as when laid, except at certain points where they were attacked by electrolysis, and where cast iron pipe in the same locality suffered to a similar extent. Numerous other cases might be noted, but those mentioned are sufficient for purposes of illustration."

Respecting Concrete Grade Aqueducts, there is a vast amount of evidence showing their substantial permanency. However, Prof. George F. Swain of Harvard University, Past President, American Society of Civil Engineers, in a paper entitled "Steel for Strength and Security," read before the American Institute of Steel Construction, in October, 1926, has pointed out certain weaknesses in the quite common conception that structures built of concrete are of substantial permanency. He calls attention to the fact that concrete is not a finished product, but made on the job, and so subject to defects such as improper grading and mixing of the various ingredients, ofttimes with very unskilled labor, and changes which take place during and after the mass has set. Concrete is porous, and the cement may be dissolved out. The effect

of salt or alkali earth is very harmful. Concrete corrodes, as steel does, but in a more harmful way. A great deal of concrete work has disintegrated and is going to pieces, and there have been many failures.

STEEL, on the other hand, comes to us as a finished product that can be tested before it is incorporated into the job, and suffers no change of constitution when it has been so used. It is not porous and cannot have its constituents washed out, and is only subject to surface oxidation, which can be prevented.

Leakage

A commonly prescribed upper limit for leakage is an amount, variously expressed, equivalent to 250 gallons per 24 hours per inch of diameter of pipe per mile. Thus a 60-inch pipe would be accepted if its leakage were 15,000 gallons per mile per day.—(American Water Works Manual, 1925.)

LEAKAGE AT LEADED JOINTS. American Civil Engineers' Handbook, 1911 (edited by Mansfield Merriman), Page 956: "It is impossible to keep lead joints permanently tight—the expansion and contraction from temperature changes are accompanied by a slight slipping of lead at each joint—settlements cause movements in the joints.

"With well tested work under average conditions a leakage of 3 gallons per 24 hours per lineal foot of lead joint under a pressure of 100 lbs. per square inch may be anticipated."

W. A. McFarland, Supt., Washington, D. C., 2,600 underground leaks in water mains found by him prior to October 28, 1911:

	Daily
1,373 service pipe leaks	13,669,000 Gals.
607 main joint leaks	8,076,000 Gals.
620 miscellaneous leaks	5,520,000 Gals.
2,600 leaks	27,265,000 Gals.

Former Commissioner Henry S. Thompson, New York City, placed water wasted by leaks in the streets from distribution on mains third in the list of principal water wastes.

T. C. Phillips, testing Chicago water mains found in 25.8 miles of streets 5,243,000 gallons per day flowing away from defective joints, services, etc. One 12-in. main leaked 1,638,000 gals. per day; nearly one-half this quantity in one block.

Leakage at Steel Pipe Line Joints. The leakage at the joints of a steel line is practically nil, whereas, in a cast-iron line employing lead joints, each connection forms a slip joint, which sooner or later may become leaky. Statistics covering twenty-two years' operation of a twenty-four inch line at Rochester, N. Y., show that of the 307 leaks developed during that period 297 were leaks at the lead joints, each one of which had to be repaired. A steel line has a riveted, caulked joint which once made tight remains so. A cast-iron line has many more joints and consequently more opportunities to leak than a steel line made up in thirty foot lengths.

Three miles of the above mentioned line at Rochester is W. I. pipe. During 40 years of continuous service, but two leaks have been discovered through the plate and both of these were on the same sheet.

During the same period 10 leaks were discovered through as many sheets of the 36-in. W. I. Rochester Conduit I, which was 3/16-in. thick and 9.6 miles long.

Superiority of LOCK-BAR PIPE

The usage of steel pipe increases in direct proportion to the working pressures and the necessity for uninterrupted service. An increasing tendency toward the use of steel pipe on distribution systems through city streets has been noticeable in recent years. On supply mains, gas lines, hydro-electric installations, etc., where such characteristics as dependability, flexibility and shock absorbing qualities are paramount, steel pipe is almost exclusively used.

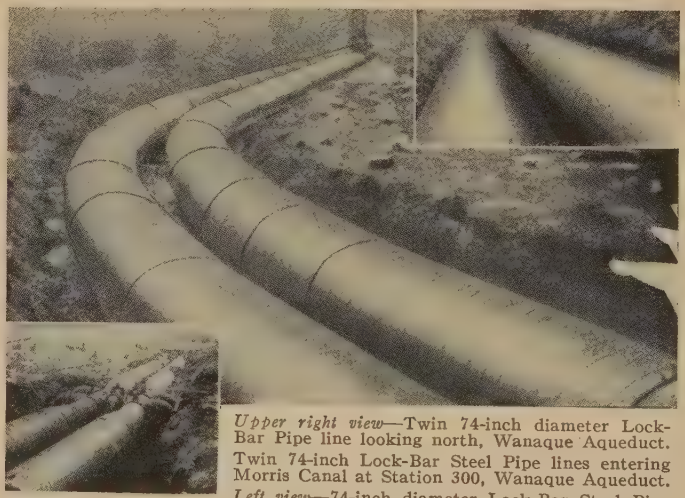
The high longitudinal joint efficiency of LOCK-BAR PIPE permits the safe utilization of a given thickness of plate against a higher working pressure than would be possible for the same plate thickness if incorporated in a pipe of lower joint efficiency. This fact is usually considered by engineers and is instrumental in effecting considerable saving in plate tonnage, particularly in long supply lines where a gradual but consistent increase of pressure is encountered.

From the severity of the specifications of materials and construction, and the complete and modern methods of fabrication of LOCK-BAR PIPE, it is evident that in no pipe works is greater precaution taken to safeguard the interests of the purchaser.

Unlike a great many manufactories, where iron is considered merely iron and steel is just steel, the Company's Engineers and Chemists are continually striving to insure that materials shall come up to specifications, and its supervisors that workmanship shall conform to the exacting standards it has set. In a word, quality is the dominant keynote and permeates the Company's entire organization. The product of this combined effort is passed on to the user of its water mains, and oil and gas lines, in the confident belief that satisfactory service, over a period of many years, will ensue.

By reason of these features LOCK-BAR PIPE is usually given preference for strength when in competition with welded pipe, and for both strength and carrying capacity when in competition with riveted pipe. In some instances this is stipulated as a 10% money preference in price on pipe laid. In others the specifications provide that riveted pipe shall be of larger diameter and of greater plate thickness than LOCK-BAR PIPE.

The elements which make for superiority are strength, carrying capacity, durability and cost. LOCK-BAR STEEL PIPE leads all others in these essential fields.



Upper right view—Twin 74-inch diameter Lock-Bar Pipe line looking north, Wanaque Aqueduct.

Twin 74-inch Lock-Bar Steel Pipe lines entering Morris Canal at Station 300, Wanaque Aqueduct.

Left view—74-inch diameter Lock-Bar Steel Pipe line and cross connection chamber north of Pompton Plains Cross Road, Station 297, Wanaque Aqueduct.

Largest Steel Pipe Contract
ever awarded in the East

The Wanaque Aqueduct contract let to the T. A. Gillespie Company by the North Jersey District Water Supply Commission calls for an expenditure of over $5,000,000. This was for 164,000 feet of 74-inch Lock-Bar Steel Pipe (about 35,000 tons of steel).

There are definite reasons of economy and service why Lock-Bar Pipe has been selected for the water supply systems of scores of prominent cities and towns of the United States and Canada.

EAST JERSEY PIPE COMPANY
7 DEY STREET, NEW YORK, N. Y.

LOCK-BAR

Before Closing

STRONG AS THE PLATE ITSELF

Temperature Stresses. Under conditions in the northern states the temperature of water and consequently of the pipe will range from 32 to 75 or 80° F., or for average conditions the range is about 45°. The pipe must be held so that it will not move with expansion and contraction. Under these conditions the change in temperature, which tends to expand or contract the pipe, uses all its force in putting it under stress. The stresses thus produced may range from nothing at the lower temperature to the maximum amount in compression at the higher temperature, or from nothing at the higher temperature to the maximum amount in tension at the lower temperature, or they may be divided, coming partly in tension at the lower temperature and partly in compression at the higher temperature. This depends on the temperature at which the pipe is laid and finally connected up. Under the most favorable conditions the stresses produced by temperature in this climate are about 9000 lb. per sq. in., and as this comes well within the strength of the steel no difficulty is occasioned by them. Ordinarily they are less than this.

Anchorages are built to keep the pipe from moving. These anchorages are formed by riveting angle irons to the steel pipe, usually four angles being attached to one 30-foot length, with a sufficient number of rivets to hold the temperature stresses, and these lengths of pipe are surrounded with concrete reinforced with steel rails of such a shape as to be capable of withstanding the computed amount of stress. The temperature push or pull on the anchorage in tons of 2000 lbs. for steel pipes of various diameters and thicknesses is shown in the last column of the table below.

Data for Steel Pipe

Diameter of Pipe	Depth of Cover		
	2 feet	4 feet	6 feet & over
	Minimum Thickness of Pipe		
30″	0.14″	0.15″	0.15″
36″	0.18″	0.20″	0.20″
42″	0.22″	0.25″	0.25″
48″	0.24″	0.31″	0.31″
54″	0.30″	0.36″	0.36″
60″	0.34″	0.41″	0.42″
66″	0.39″	0.46″	0.48″
72″	0.43″	0.52″	0.54″

Water Works System Layout

The following notes may prove useful as tersely describing the more prominent features in the development of a water works system.

Source of Supply

A water works system must secure its supply of water when and where it can most advantageously do so, and must deliver it when and where required by its customers, or "water takers." Water works structures are required to collect the water; to store it between the times when it is available until it is needed; to pump it to required elevations; to convey it from the point where it is available to the points where it is required; and to allow the water to be measured and controlled at all points. Water is required by the takers at very unequal rates, according to the requirements and emergencies that arise in their domestic and business life. The fundamental requirement controlling the design of works is to secure the ability to supply water wherever required and in whatever reasonable amounts may be needed.

Collection of Water

INTAKES are structures built out into a body of water for the purpose of drawing water for use. The position of intakes is often affected by considerations of local pollution when sewage is allowed to flow into the same body of water from which the supply is taken. This is quite commonly the case in cities located upon rivers and great lakes. The depth of intake is frequently a matter of importance where water of different qualities is obtainable at different levels. There are three types of intakes: (1) Unprotected intakes, (2) Submerged intakes, (3) Exposed or tower cribs.

UNPROTECTED INTAKES are used for small supplies. The pipe is allowed to terminate at the desired point, sometimes being protected by a coarse screen. A fine screen is not permissible because it will be speedily clogged by suspended matters carried by the water.

A Submerged Crib is a structure built on the bottom of the lake or river from the interior of which the water is taken. It serves the purpose of roughly screening the water, and also of protecting the end of the intake pipe from damage.

Exposed or Tower Cribs are structures built on the bottom of the river or lake and extending above high water. They are frequently provided at different levels with ports controlled by gates, and screens may be located in their interiors. Tower cribs have many advantages for large supplies. The ports may be closed, and water pumped out of the intake pipe, and everything inspected for tightness and condition. Screens in them may be reached for cleaning and repairs. Tower cribs require excellent foundations, and they must be built strong enough to withstand ice pressures. In cold climates they are only used for large supplies. In warmer climates, where ice pressure is not effective, they are also used for small supplies.

Intake Pipes or Conduits are the connecting channels between the intakes and the shore.

Pipes, Gates and Auxiliaries

Steel Pipes for intakes are laid in much the same way as cast-iron pipes. Flexible joints are riveted to the ends of the steel pipes where required, but the length of steel pipe between such joints may be greater, as steel pipe is stronger and more rigid than cast-iron pipe. Steel pipe is frequently designed to fit closely the contour of the bottom, and it can then be put together with ordinary flange joints bolted up by a diver.

Depth of Cover for Steel Pipe must not be excessive or the weight of the earth will flatten and deform it. A slight flattening is *not* objectionable as it does not cause the pipe to leak, and does not greatly reduce its carrying capacity.

In bad trenches and where material is slippery the depth of cover should be kept somewhat less than in solid ground. With firm material carefully placed around the pipe, and well rammed on the sides, the depth of cover for short distances may be greater than in loose caving material. If it is necessary to cover thin pipe to a great depth it may be stiffened by angle irons riveted to it at frequent intervals.

Cubic yards of earth in ditches with side slopes of one foot in ten

Bottom Width	Depth in feet											
	4	5	6	7	8	9	10	12	14	16	18	20
2 ft.	.36	0.48	0.60	0.72	0.86	0.99	1.15	1.46	1.80	2.19	2.59	2.96
2½ ft.	.44	0.57	0.71	0.85	1.01	1.16	1.33	1.68	2.06	2.48	2.92	3.33
3 ft.	.51	0.66	0.82	0.98	1.16	1.33	1.51	1.90	2.32	2.80	3.25	3.70
3½ ft.	.65	0.76	0.93	1.11	1.30	1.49	1.70	2.12	2.58	3.10	3.58	4.07
4 ft.	.66	0.84	1.04	1.24	1.45	1.66	1.88	2.34	2.84	3.40	3.91	4.44
4½ ft.	.74	0.94	1.15	1.37	1.60	1.83	2.07	2.57	3.10	3.70	4.24	4.81
5 ft.	.81	1.04	1.26	1.50	1.75	2.00	2.25	2.80	3.36	4.00	4.57	5.18

Gates on Steel Pipes. There are two ways of connecting gates in steel pipes: (1) By flange connections, the flanges being riveted to the steel pipe and bolted to flange gates. The gates must have cases heavy enough and strong enough to withstand the temperature stresses in the steel pipe. This is essential. If flange gates of ordinary construction are used the cases are sure to be broken by the expansion and contraction of the pipe. (2) The gates may be connected with the steel pipe through short pieces of cast-iron pipe and lead joints. In this case it is necessary to build anchorages on the steel pipe on either side of the gates. The two anchorages having equal and opposite temperature strains to hold may be conveniently connected by old steel rails laid in concrete.

Connections and Accessories of Gates. Gates are furnished with either flange or bell ends at about the same cost. Bell ends are generally used on pipe lines in street work; flange connections are used in gatehouses, pumping stations, and about filter plants. *Gate Boxes* are metallic boxes covering the wrench connection and gate, extending to the surface of the ground, with an expansion joint to protect them from damage by frost and traffic, and with a removable cover to allow the gate to be opened from the surface with a suitable wrench after removing the cover.

Manholes of masonry are often built about gates of special importance, large gates, and gates operated by gears, especially when located under pavements or in other places not easily accessible. It is not necessary to build such manholes

about small gates because such gates can be readily and cheaply dug up in the infrequent cases of access to them being necessary.

GEARS are used on large gates and gates under heavy pressure. In general 36-inch gates, 10 lb. per sq. in. working pressure; 30-inch gates, 50 lb. per sq. in. working pressure; and 20-inch gates, 150 lb. per sq. in. working pressure, are the smallest gates to be geared. *Spur Gears* are used on gates set vertically and opening upward, and *Beveled Gears* on gates set horizontally and opening sideways. The latter are to be used wherever the vertical space is not sufficient for the spur-geared gates.

BY-PASSES are provided in many cases on large gates operating under heavy pressures. These are built into and form part of the main gate. A small gate on the by-pass is opened to equalize the pressure in the pipe on either side of the gate before the main gate is opened. This allows the main gate to be opened with less effort than would otherwise be required.

HYDRAULICALLY OPERATED GATES in which the screws of the ordinary gate are omitted, have hydraulic cylinders provided with plungers attached directly to the moving parts. A small control valve allows high-pressure water to act on one side or the other of the plunger, opening and closing the gate. The cost is about twice that of ordinary gates.

Hydraulically operated gates with "rising screw" stems were first installed at Rochester, N. Y., at Cobbs Hill Reservoir. Surmounting the operating cylinder is a yoke upon which there is an adjustable clutch which engages the screw stem and allows the gate to be operated by hand cranks, whenever there is insufficient pressure in the Conduit for hydraulic operation.

Gates should not be placed where they cannot be inspected and tested and kept in good order.

ELECTRICALLY OPERATED GATES are furnished with electric motors geared to the screws that open and close them. Such gates are used occasionally in pumping stations and about filters where electric current is available.

SLUICE GATES are of simpler construction, arranged for building into masonry of reservoirs and other structures, and for holding water against moderate heads only. There is great

variety in the design of sluice gates. They are usually cheaper than standard gates, and for the services to which they are adapted are fully satisfactory.

Air Valves are small valves attached to pipes for the purpose of automatically letting out air. They are placed on summits only. Automatic air valves need only to be placed on summits of cast-iron pipe lines where the pressure is light and variable, that is, on summits nearly up to the hydraulic grade line. On all summits where the water is under considerable pressure it is sufficient to put a petcock or a larger valve to be opened while the pipe is being filled and which can be closed at all other times. As air is more soluble in water under pressure there is no danger of the separation of air at summits under considerable pressure, and should air be accidentally introduced to them it would be slowly dissolved and removed by the passing water. As a general rule air valves with a diameter of one inch for each foot in diameter of the water pipe are sufficient. The air valves must be protected from frost by specially constructed boxes to insure their readiness for action in winter.

For Steel Pipe air valves are also required to let air into the pipe rapidly in case of need, as the pipe is not so constituted that it will support itself against outside pressure with a vacuum in the inside. A break in a pipe at a low point, allowing the water to run out rapidly, would cause a vacuum in higher parts of the pipe, which would cause the pipe to collapse. Consideration of this feature has led to placing air valves for automatically admitting air on summits of steel pipe. Generally the air valve for this purpose should have a net area equal to a circle one-eighth of the diameter of the pipe.

Air valves are to be insisted upon in all steel-pipe lines, but it must be remembered that they are called upon to act very rarely indeed, and for this reason a defective valve or arrangement may be used without the discovery being made that it is defective, and the fact that a simpler or cheaper type of air valve has been used in certain cases where there have been no breaks and consequently no demand that has taxed its capacity is not to be taken as an indication of the sufficiency of that particular design.

Blow-offs are small pipes attached at low points for the purpose of drawing off and wasting the water contained in the

pipe during times of inspection and repair. Blow-offs are usually much smaller in diameter than the main pipe. The necessity of blow-offs depends upon the character of the water and the service of the pipe.

In general an air valve is placed on each summit and a blow-off at the bottom of each sag in a pipe conduit line. They are generally unnecessary or very infrequent in distribution mains as there are so many connections, fire hydrants, etc., which may be utilized.

Manholes consisting of saddles attached to the pipe, and removable covers capable of being bolted securely to the frame, are placed on steel pipes at distances ranging from 1000 to 2000 feet apart, to allow the pipe to be entered during construction and afterward for inspection and repair. In some cases manholes have been placed on cast-iron pipes, although most lines have been built without them.

Twin Lines of pipe are used in places of special danger. Either line will maintain at least a partial supply in case of break in the other. In case twin lines are long, there should be cross connections with gates so that in case of a break in either line a section only can be cut out, the flow at other points continuing through both lines. With this arrangement, the amount of water flowing through the system will be materially more than would flow through one line only.

The Cost of Twin Lines with cross connections is from 30 to 50 per cent greater than the cost of a single line of pipe of the same strength and capacity. Where no other purpose than safety is secured by dividing the flow, it is generally better to spend the added money, or a part of it, in strengthening one line and making it secure beyond question rather than dividing it between two smaller lines. River crossings, lines over coal fields, where there are sure to be settlements, and other points of special hazard are best crossed with twin lines.

Three Lines of Pipe Cost from 60 to 80 percent more than one line of equal strength and capacity.

Water Supply Conduits

Leakage should be avoided as far as possible. All visible leaks should be stopped and the pipe examined in open trench under test pressure.

Sand Cutting sometimes occurs where leaks develop in sharp sandy soil. A small jet from an imperfect lead joint has been known to wash sand in such a way as to cut entirely through the band of cast-iron pipe.

Tubercles in Cast-iron Pipe. The carrying capacity of cast-iron pipe is reduced in course of time by the growth of tubercles upon the interior of the pipe. In a general way the capacity of the pipe, other things being equal, is reduced from this cause by as much as one percent per annum. In small pipes the deterioration is more rapid.

Organisms. A well coated steel plate pipe has a smooth surface upon which organisms do not adhere as readily as to the rougher surface of cast-iron and concrete pipes. These growths increase during warm weather and diminish to some extent as the water gets colder in the winter.

Spring gaugings of long pipe lines which have been in use for some time show somewhat greater discharge than when the same conduits are gauged in the autumn.

Tubercles, Organic Growths and Deposits on the interior surface of pipe can be effectually removed by periodic brushing, and by scraping where brushing does not suffice. Thus the original carrying capacity of the pipe can be substantially maintained, according to the attention given to this feature of pipe line maintenance. The cost of brushing pipe is a few cents per foot, and the cost of complete scraping averages for all sizes of pipe about 12 cents per foot, the cost varying, of course, with the diameter of the pipe.

A pipe systematically brushed at fairly frequent intervals will hold its original carrying capacity remarkably well. If such periodic brushing is neglected scraping will be required since the scale formation tends to grow heavier and harder with time. Necessarily the carrying capacity of the pipe will decrease proportionately as the thickness of the scale or foreign deposits are allowed to increase.

Effect of Cleaning upon the Quality of the Water. The corrosion and tuberculation of iron pipes always adds iron rust to the water, and this iron gives it a color, tends to deposit and is objectionable. Scraping the pipes frequently increases the rate of tuberculation, and increases whatever objection there may be to iron in the water from this source.

Pressure for Domestic Service Only. At the street line 20 lb. per sq. in. will raise water to the upper floor of three-story residences and allow a fair service, but generally 40 lb. per sq. in. is the least allowance for satisfactory domestic service. For business blocks and tall buildings higher pressures are needed; 60 or 70 lb. per sq. in. is not too much to give fair service in mills and business blocks that are not especially high. High steel buildings generally pump their own water, and no effort is made to supply them without such pumping.

Pressure for Fire Service. If steam fire engines are used and depended upon as in many American cities, the only requirement for pressure is that during fires and with the heaviest draft the pipes shall have sufficient capacity to supply water to the steam fire engines and at the same time retain as much pressure as is needed for domestic service. If the pressure is higher, hose streams can be obtained from the hydrants without the use of the fire engines. The additional pressure to permit this to be done is very desirable. Seventy lbs. during fires is the lowest pressure that permits effective hose streams to be obtained for use on buildings of moderate size. If only residences are involved, 50 or 60 lbs. will give fair streams. In business districts with large buildings better hose streams are obtained with higher pressures, and in general the higher the pressure the better the fire service. One hundred lbs. gives a good working service without steam fire engines. Higher pressures up to 150 lbs. and more are available in many cities.

Reservoirs and Standpipes

Distributing Reservoirs are connected immediately with the distribution system and as near as possible to the center of population supplied. Their function is to take water when it comes and to make it available when it is needed. They are especially designed to maintain the service at times of fire and on other occasions when water is drawn rapidly. Frequently they also serve the purpose of allowing the pumps supplying the service to be shut down during certain hours of the day or at night, thereby economizing labor. This is especially the case in small plants. *Open Reservoirs* with earth embankments or masonry walls have been frequently used, and are most economical for the storage of large quantities of surface or lake waters. Ground waters and filtered waters always de-

teriorate in quality in such reservoirs, owing to the growth of certain water plants in the sunlight. *Covered Reservoirs* are always to be preferred for such waters. Roofs are sometimes used to exclude the light and keep the water from deteriorating. A light roof, not necessarily water-tight, serves this purpose.

Masonry Covers for distributing reservoirs are often used. At Washington, D. C., Springfield, Mass., and elsewhere, groined arch construction has been used. Floors to carry the weight of the roof and distribute it over the whole base are built as inverted groined arches. The piers are of concrete, as thick as 12% of the span on centers, and not more than 12 times as high as thick. If the reservoir is deep, large piers will be required to meet this condition, and the span of the arches is increased to correspond. The roof is of groined arch vaulting without reinforcing. The outside walls, with a minimum thickness of about 12% of their height at top and 16% at bottom, are braced at the bottom by the floor blocks and at the top by the roof blocks, and are calculated as reinforced beams, with breaking moment at about 43% of the distance from the bottom to the top, equal to $4h^3$, being the height of the wall in feet. In deep reservoirs economy is secured by carrying the floor on a slope of about 1 in 6 to the raised base of the walls, thereby reducing the height of the walls. The masonry is backed up by solid earth embankment, and two feet of soil is placed over the top to keep frost from the masonry. Ventilators are provided to allow the passage of air as water rises and falls in the reservoir. The top is covered with grass and shrubbery, but trees or any plants with strong heavy roots should not be planted.

Overflows should invariably be provided for distributing reservoirs and should have sufficient capacity to discharge all the water that the pipes or pumps are capable of bringing to them. Many reservoirs have been lost and great damage done by failure to provide sufficient overflow capacity.

Standpipes are elevated reservoirs built of sheet steel entirely above the surface of the ground, and are commonly used where the desired water level is a considerable distance above the surface of the ground. The limitations of steel construction do not in general allow standpipes to be used in large works. Roofs should be provided on all standpipes holding waters

deteriorating in the sunshine, that is, in general, for ground waters and filtered waters.

Reinforced concrete standpipes have been used with satisfactory results. It does not appear, however, that any very large financial saving has been made by their use. Towers of masonry are frequently built about standpipes for ornamental purposes and to protect them from wind pressure, and to make very tall standpipes, small in diameter, safe.

Elevated Steel Tanks supported on steel trestles are used in place of standpipes where the quantities of water to be stored are not large and the elevation above the surface of the ground is considerable. The East Providence tank holding 1,000,000 gallons, from 135 to 205 feet above the ground, was erected in 1904 at a cost of about $100,000. (N. E. W. W. A., vol. 19, p. 55). *Wooden Tanks* are frequently used in railway supplies and in industrial operations, but are seldom to be recommended for public water supply.

The Distribution System includes all the main pipes and lateral pipes, the standpipes and distributing reservoirs, gates, meters, all services and connections as far as owned by the water department within and near the area that is actually served with water. The piping in a distribution system must be designed so that water can be supplied to any point at any time at the greatest rate at which water may be fairly demanded at that place.

Gridiron System. This is a system in which all pipes are connected with all other pipes at street intersections, so that in case of a fire at any point water comes to that point through pipes from all directions. This arrangement is more advantageous in supplying water for fire protection than the branching system, which would be sufficient and often best for supplying water for all purposes except fire service. The gridiron system is practically universal in American cities.

An economical system for the distribution of water for routine uses only would consist of a system of branching pipes, each branch being made sufficiently large to supply the water to the territory served by it at the time of day when use is greatest.

The Gridiron System avoids "dead ends" and insures circulation. Pipes are laid below frost in the North Eastern States, with 4 to 5 feet of cover.

Gate Valves are placed at intervals on all pipe lines of considerable length. In city streets they are generally placed near intersections and so arranged, in the gridiron system, that any section may be shut out without interfering with the remainder while at the same time but a limited number of fire hydrants are affected. Outside the city valves are placed less frequently, and are best placed on summits where the pressure is least. The gates serve the purpose of facilitating tests of the pipe and shutting off portions of it for repairs in case of emergency.

Gates Smaller than the Pipe are often used on pipes 30 inches in diameter and over, connection being made by reducers on either side. The cost is less and the smaller gates are operated more quickly and easily. There is a little head lost, and the smaller the gate the more head is lost. This is controlling in determining how much smaller than the pipe it is best to make the gates.

Loss of Head in Gates with Taper Cone Connections

Diam. of gate, inches	Diameter of pipe in inches						
	30	36	42	48	54	60	72
20	1.57	3.47	6.59	....	....	....	....
24	0.65	1.57	3.07	5.40	8.72	....	....
30	0.15	0.52	1.14	2.09	3.47	5.40	11.45
36	....	0.15	0.44	0.91	1.57	2.51	5.40
42	....	....	0.15	0.40	0.75	1.25	2.83
48	....	....	....	0.15	0.35	0.65	1.57

The figures given are in velocity heads (or in feet, when the velocity in the main pipe is 8.03 ft. per sec.). They may also be taken as tenths of feet when the velocity in the main pipe is 2.54 ft. per sec.

Basis. Loss of head in a gate, 0.15, velocity head. Loss of head in cones, 0.20 of the amount that the velocity head at the throat is greater than the velocity head in the pipe.

The actual amount of head lost in a gate depends upon the form of gate, and considerable variations are to be anticipated with gates of different designs. The amount lost in the cones

depends upon the taper design and smoothness of the surfaces, and considerable variations either way are to be anticipated.

Generally 24-inch gates may be used on 30 and 36 inch pipes, 30-inch gates on 42 and 48 inch pipes, and 36-inch gates on 60 and 72 inch pipes; but if head or elevation is very valuable the gate should be one size larger than above indicated.

The usual form of valve consists of a "Body" casting connected in the line of the pipe surmounted by a "Bonnet" or "Dome" connected to the body by flanges. The "Disc" rises into the dome when the gate is opened and is actuated by a screw stem of either "rising" or "non-rising" type.

The Disc is either wedge shaped fitting into corresponding grooves in the body or is made of two parallel plates which are forced apart by folding wedges. Often the disc is seated in closing and vice versa in opening.

Water Consumption

Water consumption is of varying character. To the lay mind and the public health official it is the domestic consumption that matters chiefly. To the manufacturer and railroad official the water need of their factories and systems is one of their foremost concerns.

Water is not only used to supply the primary demands of the consumer, for drinking, bathing, culinary and general household cleansing purposes, but it is in demand for lawn sprinkling, and a vast amount of water is consumed during the summer months in this way. In the coldest winter periods, people living in poorly heated domiciles have a habit of leaving their faucets open to prevent freezing of pipes. Enormous quantities of water are needlessly wasted in lawn sprinkling and in the prevention of pipe freezing.

Street sprinkling consumes considerable quantities of water, and street flushing, practiced today to an ever increasing extent, due perhaps to the wider predominance of better pavements, takes its necessary toll of water.

Fire extinguishing is on the average a moderate water consumer, but it is not the annual volume of water so used that concerns the water works superintendent so much as the standby and relatively large volume demand for emergency fire extinguishing purposes. These calls come without warning, and must always be available in reserve.

The industrial use of water is a large percentage of the total consumption, varying from practically nothing in a strictly residential community to a very high percentage in mill towns. The industrial water demand most commonly is an eight-hour, six-day week affair; that is, the consumption may be more or less steady through eight hours of the day from Monday to Friday night. Saturday the demand falls off, and Sunday ceases practically altogether. Since all normal human activities are at their height during the daytime, the coincident industrial water consumption creates the highest normal daily peak demands.

Per Capita Water Consumption is the amount of water used per day for each person living in the city or area supplied on the basis of the annual average figures. In other words, it is the whole quantity of water supplied in gallons in one year, divided by 365 and divided by the total population of the district supplied with water. Thus the per capita consumption will vary according to the type of community. The average purely domestic consumption of water for all purposes should not be more than about 50 gallons per day, but in many cases exceeds this reasonable figure because of wanton waste or leaky plumbing fixtures.

By and large the per capita water consumption in the United States, where the average inhabitant is especially prodigal in the use of water, and where the industrial consumption is very high, ranges from around 50 to over 200 gallons per capita. In the absence of definite information, it has become a quite common practice of the engineer to tentatively assume a per capita use of 150 gallons per day in reasonably large cities.

Maximum Monthly Rate of Consumption. During that month in the year when the consumption is highest, from 15 to 25% more water is used than the average for the year. In some cases 40% more water is used.

High monthly rates of consumption are usually associated with either a very dry period, with more than the usual sprinkling of streets and lawns, or an exceptionally cold month, with a continued draft of water through many services to keep exposed and imperfectly protected pipes from freezing. Where services are metered the excess consumption in cold weather largely disappears. It is cheaper to cover the pipes or otherwise to

protect them from freezing than to pay for the water that it is necessary to allow to run in order to protect them.

Meters and Water Consumption. The general effect of meters is to reduce consumption generally by eliminating waste. It appears that the tendency is for an unmetered city to consume more than twice as much water as one which is metered. The reason is plain, of course. The consumer is required to pay exactly for what he gets. There is no guess work about it. Knowing that the water he uses is being recorded on the meter, and that he will be billed for it, the consumer cuts his waste, and repairs leaky fixtures promptly. It is perhaps a fact that the installation of meters causes the big consumer to pay even stricter attention than the small consumer to the elimination of unnecessary water consumption.

Maximum Weekly and Daily Rates. There will be some weeks and some days when the quantities will considerably exceed the average for the maximum month. Generally a maximum daily consumption of 10 or 15 gallons per capita in excess of the average for the maximum month must be expected.

Hourly Fluctuations in Flow. Water is required primarily for domestic and manufacturing purposes, and for these purposes is needed in quantities that are fairly well determined. and at times that do not vary very much from day to day. The greatest normal use of water is in the morning hours. The afternoon use is a little less. The night use of water is comparatively small.

Amount of Growth to be Anticipated. In designing pipe lines, it is necessary to anticipate growth to a certain extent in order to avoid the necessity of duplicating the lines at an early date. On the other hand, anticipating future growth to an unreasonable extent results in burdening present takers with the cost of facilities provided for the future to an unreasonable extent. In general, all new pipe lines should be designed to serve a population 50% greater than the present population, and in cases of special difficulty, where an additional line would be specially difficult or expensive, a greater growth than this should be anticipated.

Increasing the diameter of the pipe 1% increases the carrying capacity 2.63%, and increases the cost of the pipe from 1%

to 1.5%, according to the size and class of pipe and the conditions under which it is laid. On this basis adding 1% to the investment adds from 1.75% to 2.63% to the carrying capacity. $100 invested now in increasing the size of the pipe adds as much to the capacity as from $175 to $263 invested in a new pipe line at some time in the future if the new line is of the same size as the present one. $100 invested now at 5% will amount to $175 in 11 years and $263 in 20 years; at 4% the increase will be reached in 14 years and 25 years respectively. In general these represent economical limits of time to be anticipated.

As a general rule design should be made for ten or fifteen years only where the growth is over 3% per annum or where money is hard to get, and design for twenty or twenty-five years where growth is under 2% per annum or where money is obtainable at a low rate, and also in all cases where pipe is less than 12 inches in diameter or where pressure is light. There are many exceptions to this rule under peculiar conditions, and it must be applied with caution.

Population that Can be Supplied by Pipes of Various Sizes

Based on an average use of one hundred gallons per capita daily

Diameter of one pipe line, inches	For two or more pipes, sum of areas in sq. ins. Sectional area of pipe sq.ins.	With an average amount of fire service*			With no fire service. Maximum draft 170 gallons per capita daily		
		Flat slopes and long lines $V=2$	Average condition $V=3$	Steep slopes and short lines $V=4$	Flat slopes and long lines $V=2$	Average conditions $V=3$	Steep slopes and short lines $V=4$
4	13	12	27	48	660	990	1 330
6	28	61	132	228	1 490	2 240	2 950
8	50	182	392	666	2 650	3 980	5 320
10	79	425	900	1 500	4 150	6 190	8 280
12	113	835	1 720	2 850	5 950	8 950	12 000
16	201	2 320	4 620	7 400	10 600	15 900	21 300
20	314	4 940	9 520	14 900	16 500	24 800	33 200
24	452	8 900	16 700	25 500	23 900	35 800	47 800
30	707	17 200	32 000	48 000	37 400	56 100	74 800
36	1018	30 300	53 300	78 200	53 800	80 500	108 000
42	1385	46 600	80 400	117 000	73 200	110 000	146 000
48	1810	67 100	114 000	163 000	95 300	142 000	190 000
54	2290	91 600	153 000	219 000	121 000	181 000	242 000
60	2827	120 000	200 000	282 000	148 000	224 000	299 000

*Gallons daily = 120 pop. + 1 000 000 $\sqrt{\text{Pop. in thousands.}}$

Weight of Water per Cubic Foot at Different Temperatures

Temperature °F	Weight per cubic foot, pounds	Temperature °F	Weight per cubic foot, pounds	Temperature °F	Weight per cubic foot, pounds	Temperature °F	Weight per cubic foot, pounds	Temperature °F	Weight per cubic foot, pounds
32	62.42	150	61.18	260	58.55	380	54.36	500	48.7
40	62.42	160	60.98	270	58.26	390	53.94	510	48.1
50	62.41	170	60.77	280	57.96	400	53.5	520	47.6
60	62.37	180	60.55	290	57.65	410	53.0	530	47.0
70	62.31	190	60.32	300	57.33	420	52.6	540	46.3
80	62.23	200	60.12	310	57.00	430	52.2	550	45.6
90	62.13	210	59.88	320	56.66	440	51.7	560	44.9
100	62.02	212	59.83	330	56.30	450	51.2	570	44.1
110	61.89	220	59.63	340	55.94	460	50.7	580	43.3
120	61.74	230	59.37	350	55.57	470	50.2	590	42.6
130	61.56	240	59.11	360	55.18	480	49.7	600	41.8
140	61.37	250	58.83	370	54.78	490	49.2	.....	.....

Volume of Water

Cent.	Fahr.	Volume	Cent.	Fahr.	Volume	Cent.	Fahr.	Volume
4°	39.1°	1.00000	35°	95°	1.00586	70°	158°	1.02241
5	41	1.00001	40	104	1.00767	75	167	1.02548
10	50	1.00025	45	113	1.00967	80	176	1.02872
15	59	1.00083	50	122	1.01186	85	185	1.03213
20	68	1.00171	55	131	1.01423	90	194	1.03570
25	77	1.00286	60	140	1.01678	95	203	1.03943
30	86	1.00425	65	149	1.01951	100	212	1.04332

Specific Heat of Water

(From Marks and Davis's Steam Tables.)

Degrees F.	Specific heat	Degrees F.	Specific heat	Degrees F.	Specific heat	Degrees F.	Specific heat	Degrees F.	Specific heat	Degrees F.	Specific heat
20	1.0168	120	0.9974	220	1.007	320	1.035	420	1.072	520	1.123
30	1.0098	130	0.9979	230	1.009	330	1.038	430	1.077	530	1.128
40	1.0045	140	0.9986	240	1.012	340	1.041	440	1.082	540	1.134
50	1.0012	150	0.9994	250	1.015	350	1.045	450	1.086	550	1.140
60	0.9990	160	1.0002	260	1.018	360	1.048	460	1.091	560	1.146
70	0.9977	170	1.0010	270	1.021	370	1.052	470	1.096	570	1.152
80	0.9970	180	1.0019	280	1.023	380	1.056	480	1.101	580	1.158
90	0.9967	190	1.0029	290	1.026	390	1.060	490	1.106	590	1.165
100	0.9967	200	1.0039	300	1.029	400	1.064	500	1.112	600	1.172
110	0.9970	210	1.0050	310	1.032	410	1.068	510	1.117		

Pressure of Water Due to Its Weight. The pressure of still water in pounds per square inch against the sides of any pipe, channel, or vessel of any shape whatever is due solely to the "head" or height of the level surface of the water above the point at which the pressure is considered, and is equal to 0.43302 pound per square inch for every foot of head, or 62.355 pounds per square foot for every foot of head (at 62° F.)

The pressure per square inch is equal in all directions, downwards, upwards, or sideways, and is independent of the shape or size of the containing vessel.

The pressure against a vertical surface, as a retaining-wall, at any point, is in direct ratio to the head above that point, increasing from 0 at the level surface to a maximum at the bottom. The total pressure against a vertical strip of a unit's breadth increases as the area of a right-angled triangle whose perpendicular represents the height of the strip and whose base represents the pressure on a unit of surface at the bottom; that is, it increases as the square of the depth. The sum of all the horizontal pressures is represented by the area of the triangle, and the resultant of this sum is equal to this sum exerted at a point one-third of the height from the bottom. (The center of gravity of the area of a triangle is one-third of its height.)

The horizontal pressure is the same if the surface is inclined instead of vertical.

The amount of pressure on the interior walls of a pipe has no appreciable effect upon the amount of flow.

Comparison of Heads of Water in Feet with Pressures in Various Units

(From Kent's Mechanical Engineers' Pocket Book.)

One foot of water at 39.1° F. = 62.425 pounds per square foot;
One foot of water at 39.1° F. = 0.4335 pound per square inch;
One foot of water at 39.1° F. = 0.0295 atmosphere;
One foot of water at 39.1° F. = 0.8826 inch of mercury at 30° F.;
One foot of water at 39.1° F. = 773.3 feet of air at 32° F. and atmospheric pressure;
One pound on the square foot, at 39.1° F..... = 0.01602 foot of water;
One pound on the square inch, at 39.1° F..... = 2.307 feet of water;
One atmosphere of 29.922 inches of mercury.... = 33.9 feet of water;
One inch of mercury at 32° F..... = 1.133 feet of water;
One foot of air at 32° F. and 1 atmosphere..... = 0.001293 foot of water;
One foot of average sea-water..... = 1.026 feet of pure water;
One foot of water at 62° F..... = 62.355 pounds per square foot;
One foot of water at 62° F..... = 0.43302 pound per square inch;
One inch of water at 62° F. = 0.5774 ounce.... = 0.036085 pound per square inch;
One pound of water on the square inch at 62° F. = 2.3094 feet of water;
One ounce of water on the square inch at 62° F. = 1.732 inches of water.

Pressure in Pounds per Square Inch for Different Heads of Water

(At 62° F., 1 foot head = 0.433 pound per square inch; 0.433 × 144 = 62.352 pounds per cubic foot.)

Head, feet	0	1	2	3	4	5	6	7	8	9
0	.....	0.433	0.866	1.299	1.732	2.165	2.598	3.031	3.464	3.897
10	4.330	4.763	5.196	5.629	6.062	6.495	6.928	7.361	7.794	8.227
20	8.660	9.093	9.526	9.959	10.392	10.825	11.258	11.691	12.124	12.557
30	12.990	13.423	13.856	14.289	14.722	15.155	15.588	16.021	16.454	16.887
40	17.320	17.753	18.186	18.619	19.052	19.485	19.918	20.351	20.784	21.217
50	21.650	22.083	22.516	22.949	23.382	23.815	24.248	24.681	25.114	25.547
60	25.980	26.413	26.846	27.279	27.712	28.145	28.578	29.011	29.444	29.877
70	30.310	30.743	31.176	31.609	32.042	32.475	32.908	33.341	33.774	34.207
80	34.640	35.073	35.506	35.939	36.372	36.805	37.238	37.671	38.104	38.537
90	38.970	39.403	39.836	40.269	40.702	41.135	41.568	42.001	42.434	42.867

Head in Feet of Water, Corresponding to Pressures in Pounds per Square Inch

(1 pound per square inch = 2.30947 feet head; 1 atmosphere = 14.7 pounds per square inch = 33.94 feet head.)

Pressure, lbs.	0	1	2	3	4	5	6	7	8	9
0	.....	2.309	4.619	6.928	9.238	11.547	13.857	16.166	18.476	20.785
10	23.0947	25.404	27.714	30.023	32.333	34.642	36.952	39.261	41.570	43.880
20	46.1894	48.499	50.808	53.118	55.427	57.737	60.046	62.356	64.665	66.975
30	69.2841	71.594	73.903	76.213	78.522	80.831	83.141	85.450	87.760	90.069
40	92.3788	94.688	96.998	99.307	101.62	103.93	106.24	108.55	110.85	113.16
50	115.4735	117.78	120.09	122.40	124.71	127.02	129.33	131.64	133.95	136.26
60	138.5682	140.88	143.19	145.50	147.81	150.12	152.42	154.73	157.04	159.35
70	161.6629	163.97	166.28	168.59	170.90	173.21	175.52	177.83	180.14	182.45
80	184.7576	187.07	189.38	191.69	194.00	196.31	198.61	200.92	203.23	205.54
90	207.8523	210.16	212.47	214.78	217.09	219.40	221.71	224.02	226.33	228.64

Ice and Snow. (From Clark.) 1 cubic foot of ice at 32° F. weighs 57.50 pounds; 1 pound of ice at 32° F. has a volume of 0.0174 cubic foot = 30.067 cubic inches.

Relative volume of ice to water at 32° F., 1.0855, the expansion in passing into the solid state being 8.55 per cent. Specific gravity of ice = 0.922, water at 62° F., being 1.

At high pressures the melting-point of ice is lower than 32° F., being at the rate of 0.0133° F. for each additional atmosphere of pressure.

Specific heat of ice is 0.504, that of water being 1.

1 cubic foot of fresh snow, according to humidity of atmosphere, weighs 5 pounds to 12 pounds. 1 cubic foot of snow moistened and compacted by rain weighs 15 pounds to 50 pounds (Trautwine).

Fire Protection

The Requirements of Fire Service vary greatly. In European cities, with fire-proof buildings, but little water is required for the extinguishment of fire. In tropical countries, where buildings are widely separated and represent but small value, and often in wet climates, it does not pay to furnish fire service. It is better to let buildings burn now and then than to provide long and larger pipes and other equipment that would be required for fire service. In American cities wooden construction is common and wooden floors are used in many buildings having brick walls. A large pipe capacity is required to provide the water which is required for extinguishing fires in such buildings.

The Amount of Water required for extinguishing fires is not very large in the aggregate, but when fires occur it is wanted at a high rate, and pipes must therefore be provided of large capacity to meet this demand. Pipe sizes required for fire protection in American cities are always larger than those required for other uses, and the size of pipe to be selected within the area of the distribution system, and between it and the distributing reservoir or pumping station where direct pumping is used, is mainly controlled by questions of fire protection.

Water Required for Fire Service. The amount of water to be provided for fire service depends upon the size and number of fire streams required in a given area.

For Average American Conditions, take the square root of the population in thousands and this indicates the rate in millions of gallons of water per day at which water should be provided for fire service.

For example: If the population is 9 thousand allow water at the rate of 3 million gallons per day for fire service. If the population is 25 thousand allow 5 million gallons per day, and if 100 thousand allow 10 million gallons of water per day.

The pipes must be designed large enough so that the quantity of water for fire service will be available even though the fire occurs at a time when water is being used at a high rate for other purposes. It is not necessary to assume the extreme maximum rate of draft for other purposes; some chances can be taken. To find the required capacity add, first, the average

annual rate of consumption; second, 20 gallons per capita to cover ordinary fluctuations; third, the amount of water allowed for fire protection. If the fluctuations are unusually great, take 30 or 40 gallons per capita in place of 20.

Concentration of Water for Fire Service. In the case of cities up to 100,000 inhabitants it is generally necessary to provide pipe capacity so that the whole amount of water provided for fire protection can be delivered with some loss of pressure in the neighborhood of the closest, largest, highest and most valuable buildings, and at each of such points if there are several; elsewhere piping capable of delivering smaller quantities varying with the kind and value of construction and the proximity of the various buildings.

This table may be used as a very general guide. With high per capita consumption and bad fire conditions the sizes should be increased. Under opposite conditions they may be reduced. It will often pay to make pipe sizes a little smaller in the distribution and larger in the supply mains without changing the total capacity of the system.

A Standard Fire Stream is one flowing 250 gallons per minute through a smooth nozzle 1⅛ inches in diameter, with a pressure at the base of the tip of 45 pounds. Such a stream is effective to a height of 70 feet above the ground or with a horizontal carry not exceeding 63 feet. When fed through the best quality 2½-inch rubber-lined hose the hydrant pressure required to throw such a stream taken while the stream is running is as follows:

Feet of hose =	50	100	200	400	600
Lb. per sq. in. =	56	63	77	106	135

The hydrant pressure is less during the fire than at other times, because more head is lost in friction in the pipes, and the ordinary pressure must be greater to insure standard conditions during fire. The best hydrant pressure for general use is considered to be from 80 to 100 lbs., but as other conditions are frequently controlling, fire service must be largely adapted to what is available.

Perhaps the best statement of the hydraulics of fire streams and nozzles is contained in a paper by John R. Freeman, Trans. Am. Soc. C. E., 1889, vol. 21, P. 303.

48-Inch Steel Conduits, City of Newark, N. J.
Plate No. 1

These plates are reproduced from photographs showing the two riveted steel conduits, 48 inches in diameter, undermined and left unsupported for a distance of over 35 feet during a severe rain storm and flood, October 10th, 1903. In addition to the weight of the pipe and water passing through them at the rate of fifty million gallons per day, there were some 30 uprooted trees piled up over the pipe. The steel pipes supporting all this immense weight and pressure without being damaged in the least. The pipe lines are side by side, so close that only one conduit shows in the picture. These lines were built by the T. A. Gillespie Company for the East Jersey Water Company; one in 1891, the other in 1896.

48-Inch Steel Conduits
City of Newark, N. J.

Plate No. 2

The same conduits as Plate No. 1, about 50 feet further north, and shows the pipes suspended in the air, passing through one of the abutments of a culvert which had its foundations washed away by the flood. This masonry was practically supported by the two pipe lines.

Shows the same conduits near Macopin Intake, where the Pequannock River was diverted when pipes were laid, and the pipes were placed in the old river bed. The flood broke the bank of the new course, and the water washed all the earth from the pipes, which withstood the force of the torrent, although exposed for over 50 feet.

An Epitome of Steel Pipe for Large Water Mains

In giving consideration to the selection of large water supply mains of considerable length, the primary factors to be determined are the cost of material and installation, the probable life of the pipe, and its reliability to withstand safely all contingencies which local conditions may indicate as probable or even remotely possible factors tending to rupture or otherwise destroy the pipe, either through internal pressure or from external causes. A conclusion as to the probable life of the pipe, in itself a most important qualification, should not be the only factor to receive consideration.

Desirable Characteristics of Steel

In commenting upon this question Prof. George F. Swain of Harvard University, and ex-President of the American Society of Civil Engineers, in an address before the Fourth Annual Convention, American Institute of Steel Construction, held at White Sulphur Springs, West Virginia, in October, 1926, recounted the desirable characteristics of structural material, as follows:

1. Economy, which is desirable if there is equal durability and strength, and economy must take account of the cost of maintenance and ultimate replacement.
2. Durability is always desirable.
3. Strength must be sufficient for the purpose.

In commenting upon these three general characteristics Prof. Swain stresses the desirable property of usability at all times and seasons, independent of weather; and constancy, that is, not being subject to change, physical or chemical, after being put into the structure, especially not being subject to unknown changes. Another desirable characteristic is the absence of initial stresses, especially unknown and varying initial stresses, and those which cannot be removed or avoided. And finally, one of the most necessary qualifications, is reliability or freedom from risk if proper care is taken.

Steel is a finished product and the result of years of experience, experiment and study. It comes to the work in its finished form, the product of years of experience by manufacturers, metallurgists, engineers, expert superintendents and foremen, and experienced workmen. All this Prof. Swain says, and adds:

"It has, in higher degree than any other material, all the desirable qualities that have been named. It is extremely strong, durable if properly taken care of, elastic, resilient, tough, with great tensile strength, usable at all times, unchanging, and reliable. It may have initial stresses, but they may be removed or reduced by annealing, so that practically they are not dangerous. It may be tested before being used. Each heat may be tested; or each piece, if desired. It may, of course, have defects, as every material may, such as seams, segregation, piping; but there are ways of preventing these and of finding out whether they exist. Magnetic and electrical tests are being used, as well as physical tests. The chemical composition and the physical properties can be accurately controlled.

"Steel does not change after it is put into a structure. It does not crystallize under repeated loads. It is not porous.

"How much better and more reliable than concrete is a material like steel, which comes to us as a finished product that can be tested, which suffers no change of constitution when put in a structure, which is not porous and cannot have its constituents washed out, and is only subject to surface oxidation, which can be prevented.

"Steel, if stressed beyond the elastic limit, has that limit raised and becomes stronger. Steel does not fail constantly except by a fatigue or impact break, and it gives ample warning.

"Steel and iron are, as we all recognize, subject to rust, which is merely surface oxidation, and which may be prevented if care is taken. There is no internal change."

In closing his address, Prof. Swain delivered the following slogan, "Steel for Strength and Security, and you may add, Reliability."

Cost of Pipe

In selecting the class of material for large water mains, relative costs must be examined. The manufactured cost of steel pipe is less than the cost of cast iron, and freight rates

further increase the disparity, depending upon the distance between the source of manufacture and final destination of the pipe. In certain localities, therefore, the difference in cost reaches a point where it must be reckoned with, and this applies with particular emphasis to pipe 36 inches in diameter and larger, and with added force to the larger sizes. The cost of local hauling, handling and laying also should be less for steel pipe when handled in an efficient manner. The total difference in cost considered as a sinking fund, and computed at compound interest at current rates for a period of years equal to the assumed life of the steel pipe, should provide a basis for final determination respecting relative values of pipe.

Steel pipe is generally cheaper than cast-iron pipe in sizes of 24 ins. and upwards, the difference in cost increasing with ascending pressure conditions. The long 30-ft. lengths involve less field joints and bell holes, and the fact that it is lighter to handle and transport, and the greater facility and speed with which it can be laid, makes the cost of installation considerably cheaper than that of cast-iron pipe.

Consideration should also be given to the fact that likewise replacement and repair costs less with steel pipe, and can be done more quickly and consequently with less interruption of service.

The usually lower cost of steel pipe over cast-iron and other classes of pipe, effects an initial saving, which, together with the interest it will earn over a period of years, is usually enough not only to maintain the line in proper repair for life, but also to provide a sinking fund which will eventually replace it.

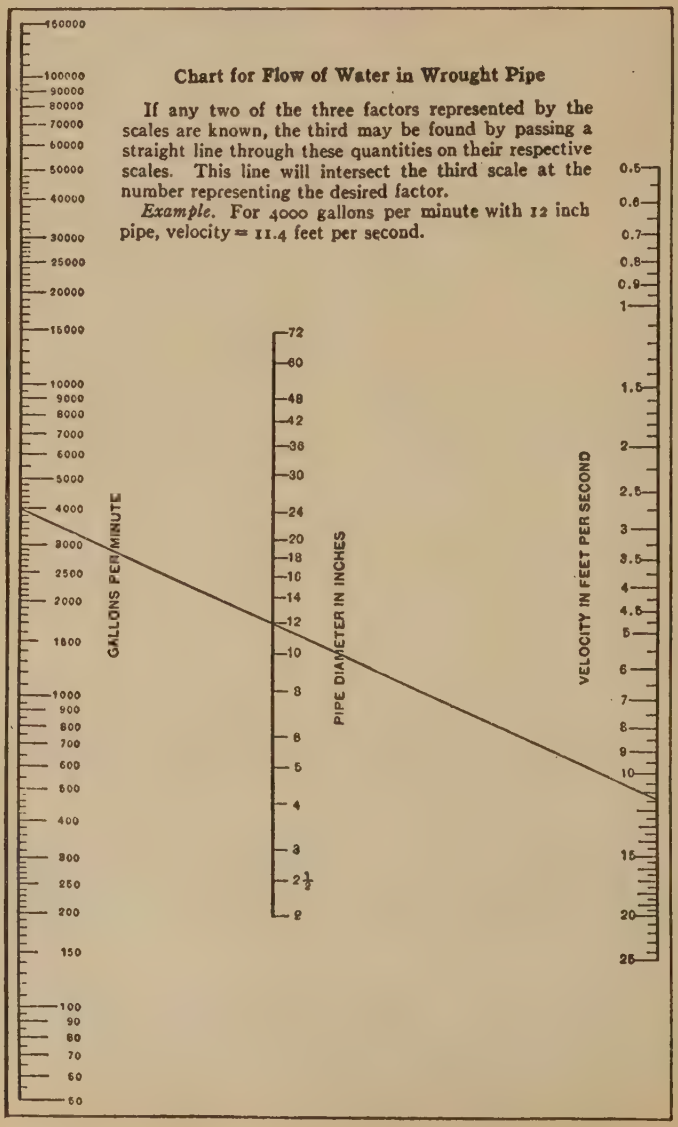
Colonel Theodore A. Leisen, in 1907, when Chief Engineer of the Water Department at Wilmington, Delaware, decided purely on economic grounds that the saving of $40,000 to the city by the adoption of steel pipe warranted its selection over cast iron.

Mr. Morris R. Sherrerd, in 1911, found that the difference in the cost of cast-iron and steel pipe for Newark, New Jersey, "was so great that we could have renewed the steel pipe in 13 or 14 years for the difference."

Chart for Flow of Water in Wrought Pipe

If any two of the three factors represented by the scales are known, the third may be found by passing a straight line through these quantities on their respective scales. This line will intersect the third scale at the number representing the desired factor.

Example. For 4000 gallons per minute with 12 inch pipe, velocity = 11.4 feet per second.



THE QUANTITY OF WATER DISCHARGED through a pipe depends on the head. If the discharge occurs freely into the air, this head is the difference in level between tbe surface of the water in the reservoir and the center of the submerged end of the pipe; if the lower end of the pipe is submerged, the head is the difference in elevation between the two water levels. The discharge for a given diameter depends also upon the length of the pipe, upon the character of its interior surface as to smoothness and upon the number and sharpness of its bends.

The head, instead of being an actual distance between levels, may be caused by pressure, as by pumping, in which case the head is calculated as a vertical distance corresponding to the pressure, 1 pound per square inch being equal to 2.309 feet head, or 1 foot head being equal to a pressure of 0.433 pound per square inch.

The total head operating to cause flow is divided into three parts: (1) The velocity head, which is the height through which a body must fall in a vacum to acquire the velocity with which the water flows in the pipe. This is equal to $v^2 \div 2g$, in which v is the velocity in feet per second, and $2g = 64.32$; (2) The entry head, which is required to overcome the resistance to entrance to the pipe. With sharp-edged entrance the entry head equals about one-half of the velocity head; with smooth, rounded entrance the entry head is inappreciable; (3) The friction head, due to the frictional resistance to flow in the pipe.

In ordinary cases of pipes of considerable length, the sum of the entry and velocity heads scarcely exceeds one foot; in the case of long pipes with low heads it is so small that it may be ignored.

When the flow becomes steady, the pipe is entirely filled throughout its length, and hence the mean velocity at any section is the same as that at the end, when the size is uniform. This velocity is found to decrease as the length of the pipe increases, other things being equal, and becomes very small for great lengths, which shows that nearly all the head has been lost in overcoming the resistances. The length of the pipe is measured along its axis, following all the curves, if there be any. The velocity considered is the mean velocity, which is equal to the discharge divided by the area of the cross section of the pipe. The actual velocities in the cross section are

greater than this mean velocity near the center and less than it near the interior surface of the pipe.

The object of the discussion of flow in pipes is to enable the discharge which will occur under given conditions to be determined, or to ascertain the proper size which a pipe should have in order to deliver a given discharge. The subject cannot, however, be developed with the definiteness which characterizes the flow from orifices and weirs, partly because the condition of the interior surface of the pipe greatly modifies the discharge, partly because of the lack of experimental data, and partly on account of defective theoretical knowledge regarding the laws of flow. In orifices and weirs errors of two or three per cent may be regarded as large with careful work; in pipes such errors are common, and are generally exceeded in most practical investigations.

It fortunately happens, however, that in most cases of the design of systems of pipes errors of five and ten per cent are not important, although they are of course to be avoided if possible, or, if not avoided, they should occur on the side of safety.

The quantity of water which flows through a pipe is the product of the area of its cross section and the mean velocity of flow. That is,

$$Q = av,$$

in which Q is the quantity discharged in cubic feet per second, a is the area in square feet and v is the velocity in feet per second.

For U. S. gallons per second multiply by	7.4805
For U. S. gallons per minute multiply by	448.83
For U. S. gallons per hour multiply by	26929.9
For U. S. gallons per 24 hours multiply by	646317.

The diagram, page 174, gives the discharge in gallons per minute, when the velocity in the pipe line is known.

Mean Velocity of Flow. The velocity of flow, depending as it does to such a great extent upon the condition of the interior surface of the pipe, is difficult to compute. Below are given the formulæ most generally accepted. In the solution of any problem a comparison of the results obtained by the use

of these formulæ is advisable. There are so many conditions affecting the flow of water that all hydraulic formulæ give only approximations to accurate results.

Approximate Formula (Trautwine). To find the velocity of water discharged from a pipe line, knowing the head, length and inside diameter, use the following formula:

$$v = m\sqrt{\frac{hD}{L+54D}},$$

in which v = approximate mean velocity in feet per second;
m = coefficient from table below;
D = diameter of pipe in feet;
h = total head in feet;
L = total length of line in feet.

Values of Coefficient "m"

Diameter of Pipe			Diameter of Pipe		
Feet	Inches	m	Feet	Inches	m
0.1	1.2	23	1.5	18	53
0.2	2.4	30	2.0	24	57
0.3	3.6	34	2.5	30	60
0.4	4.8	37	3.0	36	62
0.5	6.0	39	3.5	42	64
0.6	7.2	42	4.0	48	66
0.7	8.4	44	5.0	60	68
0.8	9.6	46	6.0	72	70
0.9	10.8	47	7.0	84	72
1.0	12.0	48	10.0	120	77

The above coefficients are averages deduced from a large number of experiments. In most cases of pipes carefully laid and in fair condition, they should give results within 5 to 10 per cent of the truth.

Example: Given the head, $h = 50$ feet, the length, $L = 5280$ feet, and the diameter, $D = 2$ feet; to find the velocity and quantity of discharge.

The value of the coefficient m from the table when $D = 2$ feet is $m = 57$.

Substituting these values in the formula, we get:

$$v=57\sqrt{\frac{50\times 2}{5280+108}}=57\sqrt{\frac{100}{5388}}=57\times 0.136=7.752 \text{ ft. per sec.}$$

To find the discharge in cubic feet per second, multiply this velocity by the area of cross section of the pipe in square feet.

Thus, $3.1416\times(1)^2\times 7.752=24.35$ cubic feet per second.

Since there are 7.48 gallons in a cubic foot, the discharge in gallons per second $=24.35\times 7.48=182.1$.

The above formula is only an approximation, since the flow is modified by bends, joints, incrustations, etc. Wrought pipes are smoother than cast-iron ones, thereby presenting less friction and less encouragement for deposits; and, being in longer lengths the number of joints is reduced, thus lessening the undesirable effects of eddy currents.

KUTTER'S FORMULA. This formula, although originally designed for open channels, can be used in the case of long pipes with low heads. It is the joint production of two eminent Swiss engineers, E. Ganguillet and W. R. Kutter, and is, properly speaking, a formula for finding the coefficient C in the well-known Chezy formula:

$$v=C\sqrt{rs},$$

in which v = mean velocity in feet per second;
r = mean hydraulic radius in feet;
s = slope = head ÷ length.

The mean hydraulic radius is the area of wet cross-section divided by the wet perimeter, which for pipes running full, or exactly half full, is equal to one-quarter of the diameter.

According to Kutter the value of this coefficient C is

$$C=\frac{41.6+\frac{0.00281}{s}+\frac{1.811}{n}}{1+\left(4.16+\frac{0.00281}{s}\right)\times\frac{n}{\sqrt{r}}}$$

in which s is the slope, r is the mean hydraulic radius in feet and n is the "coefficient of roughness." The value of n varies from

.010 for very smooth pipes to .015 for pipes in a very poor condition. For ordinary wrought pipe .012 can be used. For clean steel riveted pipe .015 can be used.

The following table gives values of the coefficient C as obtained by Kutter's formula for different slopes, hydraulic radii and degrees of roughness.

Table of Coefficient "C"

Coefficient "n"	Hydraulic radius in r feet										
	.1	.15	.2	.3	.4	.6	.8	1.0	1.5	2.0	3.0
	Slope s = .0004										
.009	104	116	126	138	148	157	166	172	183	190	199
.010	89	101	110	120	129	140	148	154	164	170	179
.011	78	90	97	107	115	126	133	138	148	154	162
.012	69	80	87	96	104	113	121	125	135	141	149
.013	62	71	78	87	94	103	110	115	124	130	138
.015	50	59	65	73	79	87	93	98	106	112	119
.017	43	50	54	62	68	75	81	85	93	98	105
	Slope s = .0010										
.009	110	121	129	141	150	161	169	175	184	191	199
.010	94	105	113	124	131	142	150	155	165	171	179
.011	83	92	99	109	117	127	134	139	149	155	163
.012	73	82	89	98	105	115	122	127	136	142	149
.013	65	74	81	89	96	104	111	116	124	130	138
.015	54	61	66	74	80	88	94	99	108	112	119
.017	45	51	57	63	69	76	82	86	93	98	105
	Slope s = .0100										
.009	110	122	130	143	151	162	170	175	185	191	199
.010	95	105	114	125	133	143	151	156	165	171	179
.011	83	93	100	111	119	129	135	141	149	155	162
.012	74	83	90	100	107	116	123	128	136	142	149
.013	66	75	81	90	98	106	112	117	125	130	138
.015	54	62	67	76	82	90	95	99	107	112	119
.017	46	52	57	64	70	77	82	87	94	99	105

For slopes steeper than .01 per unit of length, =52.8 feet per mile, C remains practically the same as at that slope. But the velocity (being $C \times \sqrt{rs}$ of course continues to increase as the slope becomes steeper.

DARCY'S FORMULA. The simplest form of Darcy's formula is

$$Cv^2 = Ds,$$

in which v is the velocity in feet per second, D is the diameter of the pipe in feet, s is the slope and C is a coefficient, varying with the diameter and roughness of the pipe. For cast-iron and wrought pipes of the same roughness, the values of C are given below. For rough pipe Darcy doubled the coefficient.

Values of "C" in Darcy's Formula

Diameter, inches	Rough pipe	Smooth pipe	Diameter, inches	Rough pipe	Smooth pipe
3	0.00080	0.00040	14	0.00065	0.000325
4	0.00076	0.00038	16	0.00064	0.00032
6	0.00072	0.00036	24	0.00064	0.00032
8	0.00068	0.00034	30	0.00063	0.000315
10	0.00066	0.00033	36	0.00062	0.00031
12	0.00066	0.00033	48	0.00062	0.00031

WILLIAMS AND HAZEN'S EXPONENTIAL FORMULA. From Chezy's formula, $v = C\sqrt{rs}$, it would appear that the velocity varies as the square root of the head; this is not true, however, for C is not a constant, but a variable depending upon the roughness of the pipe and upon the hydraulic radius and the slope. Williams and Hazen as a result of a study of the best records of experiments and plotting them on logarithmic ruled paper, found an exponential formula $v = Cr^{0.63}s^{0.54}$, in which the coefficient C is practically independent of the diameter and the slope, and varies only with the condition of the surface. In order to equalize the numerical value of C to that of the C in the Chezy formula, at a slope of 0.001, they added the factor $0.001^{-0.04}$ to the formula, so that the working formula of Williams and Hazen is

$$v = Cr^{0.63}s^{0.54}0.001^{-0.04}.$$

The value of C varies to a great extent, depending on the condition of the interior of the pipe. Computations of the exponential formula are made by logarithms or by the Williams-Hazen hydraulic slide rule.

HYDRAULIC GRADE-LINE. In a straight tube of uniform diameter throughout, running full and discharging freely into the air, the hydraulic grade-line is a straight line drawn from the discharge end to a point immediately over the entry end of the pipe, and at a depth below the surface equal to the entry and velocity heads (Trautwine).

In a pipe leading from a reservoir, no part of its length should be above the hydraulic grade-line.

AIR-BOUND PIPES. A pipe is said to be air-bound when, in consequence of air being entrapped at the high points of vertical curves in the line, water will not flow out of the pipe, although the supply is higher than the outlet. The remedy is to provide cocks or valves at the high points, through which the air may be discharged. The valve may be made automatic by means of a float.

WATER HAMMER. When a valve in a pipe is closed while the water is flowing, the velocity of the water behind the valve is retarded and a dynamic pressure is produced. When the valve is closed quickly this dynamic pressure may be much greater than that due to the static pressure, and it is then called "water hammer" or "water ram." This action is dangerous and causes in many cases fracture of the pipe. It is provided against by arrangements which prevent a rapid closing of the valve. The formulæ for the pressure produced by this shock are

$$p = 0.027 \frac{lv}{t} - po + p1, \qquad (1)$$

$$p = 63v - po + p1, \qquad (2)$$

where po = the static pressure when there is no flow, $p1$ = the static pressure when the flow is in progress, p = the maximum dynamic pressure due to the water hammer in excess over the pressure po, v = the velocity in feet per second, l = length of pipe back from the valve in feet, and t = time of closing of valve in seconds. The pressures in the formulæ are expressed in pounds per square inch. Formula (1) is to be used when t is greater than $0.000428\ l$ and formula (2) when t is equal to or less than this.

From the first of these formulæ the value of t when $p=0$ is found to be

$$t=0.027\frac{lv}{po-p1},$$

which is the time of valve closing in order that there may be no water hammer. To prevent the effects of water hammer, it is customary to arrange valves so that they cannot be closed very quickly, and the last formula furnishes the means of estimating the time required in order that no excess of dynamic pressure over the static pressure po may occur.

Formulas for Long Pipes

THE CHEZY FORMULA. If v is the velocity in the pipe, C a coefficient dependent upon roughness, density, velocity, and diameter, r the Hydraulic Radius, namely the cross-sectional area divided by the wetted perimeter, hf the frictional loss of head in a length L, and if h_f/L be designated by s the inclination or slope, then

$$v=C\sqrt{rh_f/L} \quad \text{or} \quad v=C\sqrt{rs}$$

in which for new pipes C ranges from 95 to 152 and for old pipes from 60 to 120, the value increasing both with the diameter and the velocity, as shown in the following tables:

Values of "C" in Chezy Formula for Cast-iron Pipes

Diameter of pipe, inches	Velocities in feet per second							
	For new pipes				For old pipes			
	1	3	6	10	1	3	6	10
3	95	98	100	102	63	68	71	73
6	96	101	104	106	69	74	77	79
9	98	105	109	112	73	87	80	84
12	100	108	112	117	77	82	85	88
15	102	110	117	122	81	86	89	91
18	105	112	119	125	86	91	94	97
24	111	120	126	131	92	98	101	104
30	118	126	131	136	98	103	106	109
36	124	131	136	140	103	108	111	114
42	130	136	140	144	105	111	114	117
48	135	141	145	148	106	112	115	118
60	142	147	150	152	...	...	...	...

Chezy's formula is also used for conduits and streams. The coefficient C for such cases is generally expressed in terms of r and s.

Values of "C" in Chezy Formula for Steel Riveted Pipes

Diameter of pipes, inches	Velocity in ft. per second				Diameter of pipes, inches	Velocity in ft. per second			
	1	3	5	10		1	3	5	10
3	81	86	89	92	42	102	106	108	111
11	92	102	107	115	48	105	105	105	105
11	93	99	102	105	72	110	110	111	111
15	109	112	114	117	72	93	101	105	110
38	113	113	113	113	103	114	109	106	104

Darcy's Formula. The original form of Darcy's equation was $rs = av + bv^2$, where a and b were coefficients. This Darcy later reduced to $rs = Cv^2$, where $C = c_1 + c_2 fr$. where c_1 and c_2 are constants. For new cast-iron and for wrought-iron pipes of the same roughness, Darcy's values of these constants are $c_1 = 0.0000773$ and $c_2 = 0.00000162$. The formula then reduces to

$$hf = 0.00000647 \frac{(12D+1)}{D} \frac{v^2 L}{r} \quad \text{or} \quad v = 394 \sqrt{\frac{D}{12D+1}} \sqrt{rs}$$

where D is the diameter of the pipe in feet. For rough pipe Darcy reduced the velocity one-half. Darcy's formula may be transposed to $CV^2 = Ds$, in which case C has an average value of 0.00032 for clean pipes of diameters from 8 to 48 inches inclusive, the variation being only 3% from the mean for all except the 8-inch.

Fanning's Formula for flow in pipes is

$$h_f = \frac{4fL}{D} \frac{v^2}{2g} \quad \text{or} \quad v = \sqrt{\frac{2gDh_f}{4fL}}$$

where f is a coefficient which ranges from 0.0071 to 0.0028 for new pipes and from 0.0152 to 0.00046 for old ones, the value decreasing as diameter and velocity increase. The other notation is the same as that at the beginning of this article.

Values of "F" in Fanning's Formula for Cast-iron Pipes

Diameter of pipe, inches	Velocity in feet per second							
	For new pipes				For old pipes			
	1	3	6	10	1	3	6	10
3	.0071	.0067	.0064	.0062	.0152	.0139	.0128	.0122
6	.007	.0063	.006	.0057	.0135	.0117	.0108	.0103
9	.0067	.0058	.0055	.0051	.0122	.0105	.010	.0092
12	.0064	.0056	.0051	.0048	.0108	.0096	.0089	.0084
15	.0062	.0053	.0048	.0043	.0099	.0087	.0081	.0078
18	.0058	.0051	.0045	.0041	.0087	.0078	.0073	.0069
24	.0053	.0045	.0040	.0037	.0076	.0067	.0063	.0060
30	.0046	.0040	.0037	.0035	.0067	.0061	.0057	.0055
36	.0042	.0037	.0035	.0033	.0061	.0056	.0052	.0050
42	.0038	.0035	.0033	.0031	.0058	.0052	.005	.0048
48	.0036	.003	.0031	.0029	.0057	.0051	.0049	.0046
60	.0032	.0030	.0029	.0028				

Tables for Long Pipes are given on the three following pages. The friction factors $4f$ used in computing them differ slightly from those at the foot of the preceding page and are the same as those given in "Merriman's Treatise on Hydraulics." These tables apply to new, clean, straight cast-iron and wrought-iron pipes, either smooth or coated with coal tar, and laid with close joints. A pipe is said to be long when its length is such that the error in computing v by the last formula does not exceed five per cent.; this will usually be the case when the length of pipe is greater than 1000 diameters.

The discharges given in the tables are accurate in the last figure for the given velocities. Thus for a velocity of 3.4 ft. per sec. the discharges for pipes 6 and 16 in. in diameter are 40.1 and 285 cu. ft. per min. The friction head, given in the second column under each size of pipe, is however, liable to an error of one or two units in the second figure; thus for 3.4 ft. per sec., in the 6-inch pipe the head 0.88 per 100 ft. may actually range from 0.86 to 0.90 for new, clean pipes.

Velocities and Discharges for a given pipe may be found from the tables when the friction head is known. For example, let a pipe 3500 ft. long and 6 in. in diameter have a total head of 37.8 ft. Here the friction head per 100 ft. is $100 \times 378/3500 = 1.08$, whence from the table velocity $= 3.8$ ft. per sec., and

discharge = 44.8 cu. ft. per min. Again, let an 8-in. pipe 6075 ft. long be under a head of 112.5 ft., then friction head per 100 ft. is $100 \times 112.5/6075 = 1.85$, whence velocity = 6.1 ft. per sec., and discharge = 199 cu. ft. per sec. These are for new, clean, straight iron pipes. Curves influence results but little unless they are very sharp.

For Old Pipes the actual heads should be multiplied by the following numbers before using the table to obtain velocities and discharges:

For diameter,	3	6	12	16	24	30	36 in.
Multiplier....	0.50	0.55	0.60	0.62	0.64	0.65	0.66

For example, let an old pipe 3500 ft. long and 6 in. diameter be under an actual head of 37.8 ft. or 1.08 ft. per 100 ft.; the true friction head is $0.55 \times 1.08 = 0.59$ ft. per 100 ft., whence from the table velocity = 2.8 ft. per sec. and discharge = 33 cu. ft. per sec. Similarly, for given velocities the true friction heads are found approximately by multiplying the tabular values by the following numbers:

For diameter,	3	6	12	16	24	30	36 in.
Multiplier....	2.00	1.81	1.67	1.61	1.56	1.54	1.52

For example, for a velocity of 60 ft. per sec. the friction head in an old pipe of 12 in. diameter is 1.87 instead of 1.12 ft. per 100 ft. The term old pipe is a vague one and refers to the amount of corrosion and incrustation rather than to the actual life in years.

The Required Diameter for a pipe to furnish a given discharge under a given head may also be roughly found from the tables. For example, to find diameter to furnish 100 cu. ft. min. under a head of 1.2 ft. per 100 ft.: for a new, clean pipe the table gives 8 inches as required diameter, for an old pipe, assume multiplier as 0.5, then head becomes 0.60 ft. per 100 ft. and the table shows that a 10-in. pipe is somewhat too large.

The formula for computing the diameter of a long pipe is: $D = 0.479\ (4flq^2/h^{1/5})$, in which q = discharge in cu. ft. per min., h = head in ft., l = length of pipe in ft., D = diameter of pipe in ft., and a rough mean value of f being taken as 0.005 for new pipe. After D is computed the velocity is found by $v = q/\frac{1}{4}\pi D2$ and thus a better value of f may be obtained from the last

preceding 12-line table. Then a new diameter may be recomputed if the change in f seems to warrant it.

For example, to find the diameter of a new pipe to deliver 67 cu. ft. per sec. under a head of 24 ft., its length being 4500 ft. Using $4f$ as 0.020, the formula gives $D = 3.35$ ft., whence $v = 6.6$ ft. per sec. Then from the last preceding 12-line table a closer value of f is found to be 0.0061, or $4f = 0.025$. A second computation now gives $D = 3.52$ ft., so that a 42-inch pipe should be used. With the same data the rough value of $4f$ for an old pipe is 0.035 and D is about 48 inches.

KUTTER. The Kutter formula was designed for open channels and will be treated under that head. It is sometimes used for pipes, but the results from it, since the coefficients, like those of the Chezy and Fanning formulas, change with the velocity in the same pipe, are usually erroneous, except for a very small range of velocity. For this reason it is not to be recommended for general use in computations for pipes.

Exponential Formula for Pipes

One form of an exponential formula for flow of water in pipes is

$$h_f = Kv^N L/D^{1.25}$$

where the notation is the same as that at beginning of page 189, but where the coefficients K and N may vary with the kind and condition of the pipe. To avoid zeros in the coefficient a unit length of 1000 feet may be taken, when the formula becomes

$$h_f = \frac{Kv^N}{D^{1.25}} \cdot \frac{L}{1000}$$

in which N has a mean value of 1.87 and K ranges from 0.28 to 0.48 with an average value of 0.38 for ordinarily clean pipes. For rough or tuberculated pipes K may become as high as 0.70. The advantage of the exponential formula is that the coefficient for the same pipe is nearly constant and, if the exponent, its range being from 1.70 to 2.00, be properly selected, absolutely so, and the variation in all cases is much less than with other formulas, so that with a few average coefficients for different

classes of channels, all hydraulic flow problems may be solved with reasonable accuracy without reference to any tables of coefficients. The foregoing formula with the coefficient 0.38 may be expected to give results within 20% of accuracy for any pipes likely to be encountered which have diameters from one inch to fifteen feet, except those extremely tuberculated, and with velocities from 1 foot to 20 feet per second. For ordinary cast-iron or riveted pipe with any diameter and velocity, the results may be expected to be within 6% of accuracy.

The exponential formula is derived from experiment in the following manner: Any plane curve passing through the origin of coordinates can be represented by an equation of the form $y = mxN$, in which m and N may be either constant or variable. If the curve be one of single curvature such that the change of inclination of its tangents either continuously increases or continuously decreases, both m and N become constants. All curves which are loci of equations expressing the relation between velocity and loss of head in flowing water are of this latter class, and consequently $hf = mvN$ is a general expression for the loss of head in either a pipe or an open channel. If for any pipe line the values of m and N be determined, the equation of flow in that line is established. Expressing the above equation for logarithmic computation, it becomes

$$\log h_f = \log m \div N \log v$$

and considering the logarithms as mere quantities, this is at once seen to be the equation of a straight line in which $\log m$ is the intercept on the hf axis and N is the tangent of the angle which the line makes with the v axis. Both m and N may be found by determining two points in the line representing the plottings of the logarithms. If it be desired to draw the straight line which most nearly coincides with a number of points, it must pass through their center of gravity and also through the centers of gravity of the two groups into which the center of gravity of the whole divides them. Having the last two points, the equation of the line is readily determined.

The following example will serve to illustrate the process. The data are from observations on a 12-inch cast-iron water main very carefully laid in a tangent some 3500 feet long, the loss in 1000 feet of which was measured.

C = center of gravity or mean point of the whole group
A = center of gravity of part of group above C
B = center of gravity of part of group below C
$Ch = hf$ coordinate of C, $Cv = v$ coordinate of C
$Ah = hf$ coordinate of A, $Av = v$ coordinate of A
$Bh = hf$ coordinate of B, $Bv = v$ coordinate of B

Observed Data

No.	v Ft. per sec.	hf Ft. of water	Logarithms log v		log hf	
1	4.794	6.515	0.6807		0.8139	
2	4.667	5.577	.6690	Sum = 3.1667	.7464	Sum = 3.4641
3	4.155	5.100	.6186	Mean = 0.63334	.7076	Mean = 0.69282
4	3.998	4.002	.6018	$= Av$	.6023	$= Ah$
5	3.950	3.926	.5966		.5939	
6	3.519	3.566	.5464		.5522	
7	3.252	2.888	.5122	Sum = 2.3715	.4606	Sum = 2.0046
8	3.208	2.942	.5062	Mean = 0.47430	.4686	Mean = 0.40092
9	2.943	2.374	.4688	$= Bv$	.3755	$= Bh$
10	2.177	1.405	.3379		.1477	

Sum = 5.5382 Sum = 5.4687
Mean = 0.55382 = Cv Mean = 0.54687 = Ch

$Av - Cv = 0.63334 - 0.55382 = 0.07952$
$Cv - Bv = 0.55382 - 0.47430 = 0.07952$
$Ah - Ch = 0.69282 - 0.54687 = 0.14595$
$Ch - Bh = 0.54687 - 0.40092 = 0.14595$

Since $Av - Cv = Cv - Bv$ and $Ah - Ch = Ch - Bh$, the three points A, C, and B are in a straight line, which fact checks the accuracy of the work.

N = tangent of inclination of line ACB

$$= \frac{Ah\text{-}Ch}{Av\text{-}Cv} = \frac{Ch\text{-}Bh}{Cv\text{-}Bv} = \frac{Ah\text{-}Bh}{Av\text{-}Bv} = \frac{0{\cdot}14592}{0{\cdot}07952} = 1{\cdot}835$$

Since $\log m = \log hf - n \log v$, using the coordinate of C
$\log m = 0.54687 - 1.835 \times 0.55382$
$= 0.54687 - 1.01626 = 9.53051 = \log 0.3393$, and $m = 0.3393$

The equation for this 12-inch pipe is therefore $hf = 0.3393\ v1.835\ L/1000$.

Remark: Evidently the v coordinates must be divided between the same pair of observations as the hf coordinates. The mathematical determination of what group should include a point whose v coordinate is on one side of C and whose hf coordinate is on the other, depends on whether the point itself is above or below a normal to the line ACB through C. This can usually be established by plotting the logarithms on ordinary cross-section paper, or the observations on logarithmic paper.

To introduce the diameter into the equation, a series of values of m and N for pipes of different diameters must be obtained. The range of N is relatively small, the limits for all reliable pipe experiments on record being from 1.70 to 2.08, and if the pipes are of the same character of surface and alignment the value of N will be constant. It is, therefore, only necessary to consider the variation of m, which depends upon the area of the cross-section or upon D and upon the roughness. Evidently m varies inversely as some power of the diameter, and for $1/D = 0$, $m = 0$ for any velocity, so the curve representing the relation between m and D will be $m = KD - x$. Proceeding in the same manner as before an average value of $x = 1.25$ will be obtained, and the formula for pipe of the same character as that in the above experiment is

$$h_f = \frac{Kv^{1.835}}{D^{1.25}} \cdot \frac{L}{1000} \quad \text{or} \quad h_f = \frac{0.38v^{1.87}}{D^{1.25}} \cdot \frac{L}{1000}$$

for average conditions, and this may be transposed to

$$v = 73.54D^{0.668}S^{0.535} \quad \text{or} \quad v = 185r^{0.668}s^{0.535}$$

Variations in Diameter

Relation of Diameter of Pipe to Quantity Discharged. In terms of C for Chezy's formula.

$$Q = \pi/8C\sqrt{sD^5}$$

in terms of Fanning's coefficient f, $Q = \pi/4\sqrt{\frac{2g}{4f} \cdot \frac{hf}{L} \cdot D^5}$

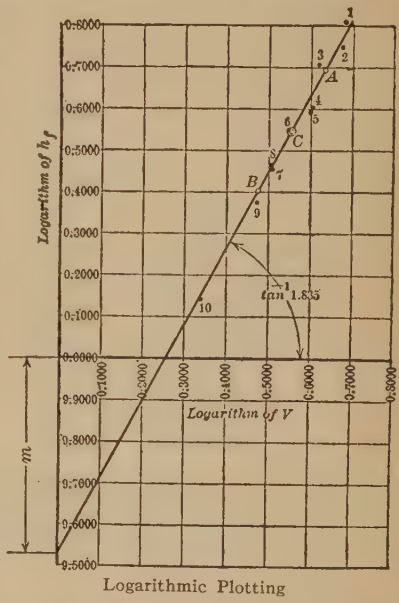
Approximately for rough pipe $Q = 1000\ D^5/_2 s^1/_2$

and for smooth pipe $Q = 2 \times 1000\ D^5/_2 s^1/_2$

Roughness. The effect of roughness in a water pipe is in general to retard the flow or increase the loss in head. This is accomplished by reducing the velocity of the water at the surface of contact, thus producing a general reduction in velocity and also causing cross currents or eddies which use up the energy in the stream. Roughness decreases C and increases f and K in the foregoing formulas. It also increases N somewhat in the exponential formula.

Curvature. The effect of curvature is to increase the loss of head. This increased loss is partly due to the cross currents and eddies set up in the bend, but also to the changes of velocity along the stream lines and increased friction along the walls of

the channels due to increased velocities over part of the circumference. The loss of head due to a curve may be stated in terms of the velocity head hv or, better, in terms of the equivalent length of straight pipe which would give the same loss as the curve. Experiments upon the loss of head in pipes show the radius of the curve of minimum resistance for a right-angled bend to be about three diameters of the pipe. For six-inch pipe the loss due to such a curve is about the same as that in eight feet of straight pipe, and for a thirty-inch pipe about the same as that in forty feet of straight pipe. For intermediate sizes the loss may be expected to fall between these limits and to vary approximately as the diameter



Logarithmic Plotting

EXPANSIONS when sudden always produce eddies which increase the loss of head. Consider two sections of a pipe, 1 and 2; 1 to be taken at a point where normal condition of flow exists before expansion and 2 after expansion.

If v^1 and v^2 are the velocities and A^1 and A^2 the areas at the two sections then the loss of head due to this sudden enlargement

$$hfe = \frac{(v_1 - v_2)^2}{2g} \text{ or } hfe = \left[\frac{A_2}{A_1} - 1\right]^2 \frac{v_2^2}{2g}$$

According to St. Venant, this quantity should be increased by $v^2/18g$, but this correction is so small as a rule that it can be neglected, and more recent experiments indicate that the formula is as likely to give results in excess as otherwise.

CONTRACTION when sudden produces an effect upon a stream very similar to a sharp orifice; that is, just beyond the contraction occurs the point of minimum cross-section of the

stream or the "vena contracta." There result not only the loss of head due to the contraction of the stream, but also that due to the reenlargement of it after passing the "vena contracta." If v is the velocity under conditions of normal flow in the pipe after passing the contraction and C is the coefficient of contraction, the same in this case as for a sharp orifice, then the loss of head due to the contraction is

$$hfc = \frac{v^2}{2g}\left[\frac{1}{C} - 1\right]^2$$

According to St. Venant this quantity should be increased by $v^2/18g$. Also it may be written $hfc = Ccv^2/2g$, where Cc varies from 0.42 to 0.53. A fair assumption to make is $Cc = 0.5$. This may also be taken as the loss of head due to sharp-edged entrance into a pipe. The value of C is probably too high for small pipes and too low for large pipes.

Obstructions. If the sectional area of a pipe be gradually decreased and then gradually increased as in the case of a Venturi meter, the loss of head for moderate velocities is not much increased over that due to normal flow. When the obstruction causes a sudden contraction or expansion of the stream or there is discontinuity of the pipe wall, the loss of head is increased.

Valves. The losses due to valves in pipe lines have been investigated with accuracy in only a few instances. From these experiments it appears that a fully open gate valve in a pipe causes a loss of head corresponding to about six diameters of length of the pipe.

Measurement of Flowing Water

(From Kent's Mechanical Engineers' Pocket Book.)

Piezometer. If a vertical or oblique tube be inserted into a pipe containing water under pressure, the water will rise in the former, and the vertical height to which it rises will be the head producing the pressure at the point where the tube is attached. Such a tube is called a piezometer or pressure measure. If the water in the piezometer falls below its proper level it shows that the pressure in the main pipe has been reduced by an obstruction between the piezometer and the reservoir. If the water rises above its proper level it indicates that the pressure there has been increased by an obstruction beyond the piezometer.

If we imagine a pipe full of water to be provided with a number of piezometers, then a line joining the tops of the columns of water in them is the hydraulic grade-line.

Pitot Tube. The Pitot tube is used for measuring the velocity of fluids in motion. It has been used with great success in measuring the flow of natural gas. (S. W. Robinson, Report Ohio Geol. Survey, 1890.) (See also Van Nostrand's Mag., Vol. XXXV). It is simply a tube so bent that a short leg extends into the current of fluid flowing from a tube, with the plane of the entering orifice opposed at right angles to the direction of the current. The pressure caused by the impact of the current is transmitted through the tube to a pressure-gage of any kind, such as a column of water or of mercury, or a Bourdon spring-gage. From the pressure thus indicated and the known density and temperature of the flowing fluid is obtained the head corresponding to the pressure, and from this the velocity. In a modification of the Pitot tube described by Professor Robinson, there are two tubes inserted into the pipe conveying the gas, one of which has the plane of the orifice at right angles to the current, to receive the static pressure plus the pressure due to impact; the other has the plane of its orifice parallel to the current so as to receive the static pressure only. These tubes are connected to the legs of a U tube partly filled with mercury, which then registers the difference in pressure in the two tubes, from which the velocity may be calculated. Comparative tests of Pitot tubes with gas-meters, for measurements of the flow of natural gas, have shown an agreement within 3%.

It appears from experiments made by W. M. White, described in a paper before the Louisiana Eng's Socy., 1901, by Williams, Hubbell and Fenkel (Trans., A. S. C. E., 1901), and by W. B. Gregory (Trans, A. S. M. E., 1903), that in the formula for the Pitot tube, $V = c\sqrt{2gH}$, in which V is the velocity of the current in feet per second, H the head in feet of the fluid corresponding to the pressure measured by the tube, and c an experimental coefficient, $c = 1$ when the plane at the point of the tube is exactly at right angles with the direction of the current, and when the static pressure is correctly measured. The total pressure produced by a jet striking an extended plane surface at right angles to it, and escaping parallel to the plate, equals twice the product of the area of the jet into the

pressure calculated from the "head due to the velocity," and for this case $H = 2 \times \frac{V^2}{2g}$, instead of $\frac{V^2}{2g}$; but as found in White's experiments the maximum pressure at the point on the plate exactly opposite the jet corresponds to $h = \frac{V^2}{2g}$. Experiments made with four different shapes of nozzles placed under the center of a falling stream of water showed that the pressure produced was capable of sustaining a column of water almost exactly equal to the height of the falling water.

Tests by J. A. Knesche (Indust. Eng'g, Nov., 1909), in which a Pitot tube was inserted in a 4-inch water pipe, gave C = about 0.77 for velocities of 2.5 to 8 feet per second, and smaller values for lower velocities. He holds that the coefficient of a tube should be determined by experiment before its readings can be considered accurate.

Maximum and Mean Velocities in Pipes. Williams, Hubbell and Fenkel (Trans. A. S. C. E., 1901) found a ratio of 0.84 between the mean and the maximum velocities of water flowing in closed circular conduits, under normal conditions, at ordinary velocities; whereby observations of velocity taken at the center under such conditions, with a properly rated Pitot tube, may be relied on to give results within 3% of correctness.

The Venturi Meter, invented by Clemens Herschel, and described in a pamphlet issued by the Builders' Iron Foundry of Providence, R. I., is named for Venturi, who first called attention, in 1796, to the relation between the velocities and pressures of fluids when flowing through converging and diverging tubes. It consists of two parts,—the tube, through which the water flows, and the recorder, which registers the quantity of water that passes through the tube. The tube takes the shape of two truncated cones joined in their smallest diameters by a short throat-piece. At the up-stream end and at the throat there are pressure-chambers, at which points the pressures are taken.

The action of the tube is based on that property which causes the small section of a gently expanding frustum of a cone to receive, without material resultant loss of head, as much water at the smallest diameter as is discharged at the large end, and on that further property which causes the pressure of the

water flowing through the throat to be less, by virtue of its greater velocity, than the pressure at the up-stream end of the tube, each pressure being at the same time a function of the velocity at that point and of the hydrostatic pressure which would obtain were the water motionless within the pipe.

The recorder is connected with the tube by pressure-pipes which lead to it from the chambers surrounding the up-stream end and the throat of the tube. It may be placed in any convenient position within 1000 feet of the meter. It is operated by a weight and clockwork. The difference of pressure or head at the entrance and at the throat of the meter is balanced in the recorder by the difference of level in two columns of mercury in cylindrical receivers, one within the other. The inner carries a float, the position of which is indicative of the quantity of water flowing through the tube. By its rise and fall the float varies the time of contact between an integrating drum and the counters by which the successive readings are registered.

There is no limit to the sizes of the meters nor the quantity of water that may be measured. Meters with 24-inch, 36-inch, 48-inch, and even 20-foot tubes can be readily made.

Measurement by Venturi Tubes (Trans. A. S. C. E., Nov., 1887, and Jan., 1888). Mr. Herschel recommends the use of a Venturi tube inserted in the force main of the pumping engine, for determining the quantity of water discharged. Such a tube applied to a 24-inch main has a total length of about 20 feet. At a distance of 4 feet from the end nearest the engine the inside diameter of the tube is contracted to a throat having a diameter of about 8 inches. A pressure gage is attached to each of two chambers, the one surrounding and communicating with the entrance or main pipe, the other with the throat. According to experiments made upon two tubes of this kind, one 4 inches in diameter at the throat and 12 inches at the entrance, and the other about 36 inches in diameter at the throat and 9 feet at its entrance, the quantity of water which passes through the tube is very nearly the theoretical discharge through an opening having an area equal to that of the throat, and a velocity which is that due to the difference in head shown by the two gages. Mr. Herschel states that the coefficient for these two widely varying sizes of tubes, and for

a wide range of velocity through the pipe, was found to be within 2%, either way, of 98%. In other words, the quantity of water flowing through the tube per second is expressed within two per cent by the formula $W = 0.98\ A\sqrt{2gh}$, in which A is the area of the throat of the tube, h the head, in feet, corresponding to the difference in the pressure of the water entering the tube and that found at the throat, and $g = 32.16$.

The Miner's Inch

(From Merriman's Treatise on Hydraulics.)

The miner's inch may be roughly defined to be the quantity of water which will flow from a vertical standard orifice one inch square, when the head on the center of the orifice is 6½ inches. The coefficient of discharge is about 0.623, and accordingly the actual discharge from the orifice in cubic feet per second is

$$q = \frac{1}{144} \times 0.623 \times 8.02 \sqrt{\frac{6.5}{12}} = 0.0255,$$

and the discharge in one minute is $60 \times 0.0255 = 1.53$ cubic feet. The mean value of one miner's inch is therefore about 1.5 cubic feet per minute.

The actual value of the miner's inch, however, differs considerably in different localities. Bowie states that in different counties of California it ranges from 1.20 to 1.76 cubic feet per minute. The reason for these variations is due to the fact that when water is bought for mining or irrigating purposes, a much larger quantity than one miner's inch is required, and hence larger orifices than one square inch are needed. Thus at Smartsville, a vertical orifice or module, 4 inches deep and 250 inches long, with a head of 7 inches above the top edge, is said to furnish 1000 miner's inches. Again at Columbia Hill, a module 12 inches deep and 12¾ inches wide, with a head of 6 inches above the upper edge, is said to furnish 200 miner's inches. In Montana the customary method of measurement is through a vertical rectangle, one inch deep, with a head on the center of the orifice of 4 inches, and the number of miner's inches is said to be the same as the number of linear inches in the rectangle; thus under the given head an orifice one inch deep and 60 inches long would furnish 60 miner's inches. The

discharge of this is said to be about 1.25 cubic feet per minute, or 75 cubic feet per hour.

The following are the values of the miner's inch in different parts of the United States. In California and Montana it is established by law that 40 miner's inches shall be the equivalent of one cubic foot per second, and in Colorado 38.4 miner's inches is the equivalent. In other States and Territories there is no legal value, but by common agreement 50 miner's inches is the equivalent of one cubic foot per second in Arizona, Idaho, Nevada, and Utah; this makes the miner's inch equal to 1.2 cubic feet per minute.

A module is an orifice which is used in selling water, and which under a constant head is to furnish a given number of miner's inches, or a given quantity per second. The size and proportions of modules vary greatly in different localities, but in all cases the important feature to be observed is that the head should be maintained nearly constant in order that the consumer may receive the amount of water for which he bargains, and no more.

The simplest method of maintaining a constant head is by placing the module in a chamber which is provided with a gate that regulates the entrance of water from the main reservoir or canal. This gate is raised or lowered by an inspector once or twice a day so as to keep the surface of the water in the chamber at a given mark. This plan is a costly one, on account of the wages of the inspector, except in works where many modules are used and where a daily inspection is necessary in any event, and it is not well adapted to cases where there are frequent and considerable fluctuations in the surface of the water in the feeding canal.

Numerous methods have been devised to secure a constant head by automatic appliances; for instance, the gate which admits water into the chamber may be made to rise and fall by means of a float upon the surface; the module itself may be made to decrease in size when the water rises, and to increase when it falls, by a gate or by a tapering plug which moves in and out and whose motion is controlled by a float. These self-acting contrivances, however, are liable to get out of order, and require to be inspected more or less frequently. Another method is to have the water flow over the crest of a weir as soon as it reaches a certain height.

The use of the miner's inch, or of a module, as a standard for selling water, is awkward and confusing, and for the sake of uniformity it is greatly to be desired that water should always be bought and sold by the cubic foot per second. Only in this way can comparison readily be made, and the consumer be sure of obtaining exact value for his money.

The following table gives the discharge in cubic feet per minute of a miner's inch of water, as measured under the various heads and different lengths and heights of apertures used in California.

Miner's Inch Measurements

(Pelton Water Wheel Company)

Length of opening in inches	Opening 2 inches high			Opening 4 inches high		
	Head to center, 5 inches	Head to center, 6 inches	Head to center, 7 inches	Head to center, 5 inches	Head to center, 6 inches	Head to center, 7 inches
	Cubic feet	Cubic feet	Cubic feet	Cubic feet	Cubic feet	Cubic feet
4	1.348	1.473	1.589	1.320	1.450	1.570
6	1.355	1.480	1.596	1.336	1.470	1.595
8	1.359	1.484	1.600	1.344	1.481	1.608
10	1.361	1.485	1.602	1.349	1.487	1.615
12	1.363	1.487	1.604	1.352	1.491	1.620
14	1.364	1.488	1.604	1.354	1.494	1.623
16	1.365	1.489	1.605	1.356	1.496	1.626
18	1.365	1.489	1.606	1.357	1.498	1.628
20	1.365	1.490	1.606	1.359	1.499	1.630
22	1.366	1.490	1.607	1.359	1.500	1.631
24	1.366	1.490	1.607	1.360	1.501	1.632
26	1.366	1.490	1.607	1.361	1.502	1.633
28	1.367	1.491	1.607	1.361	1.503	1.634
30	1.367	1.491	1.608	1.362	1.503	1.635
40	1.367	1.492	1.608	1.363	1.505	1.637
50	1.368	1.493	1.609	1.364	1.507	1.639
60	1.368	1.493	1.609	1.365	1.508	1.640
70	1.368	1.493	1.609	1.365	1.508	1.641
80	1.368	1.493	1.609	1.366	1.509	1.641
90	1.369	1.493	1.610	1.366	1.509	1.641
100	1.369	1.494	1.610	1.366	1.509	1.642

Weirs

Sharp-edged Weirs. When an obstruction is placed in an open channel, so that water is caused to flow over it, it is called a dam or weir. If the top of the weir be a thin straight edge, the conditions of flow are similar to those that would exist in an orifice in a thin wall if the side contractions were suppressed and the head fell so low that the water did not fill the orifice to its top. If the portions of the dam near the walls of the channel are raised above the level of the rest so that water does not flow over them, the overflowing jet is contracted at the sides as in the case of an orifice. The general expression for the discharge of water over a weir is

$$Q = \tfrac{2}{3} C L H \sqrt{2gH}$$

wherein H is the height above the crest of the weir to the level of still water and L is the length of the crest over which the water flows. Practically, it is not possible to measure H, but a head h may be observed to the surface of the stream above the curve of depression caused by the weir, and to this velocity head hv due to the velocity v_a with which the water approaches the weir, may be added when the result is approximately equal to H. If the velocity of approach be small, h as observed may be treated as equal to H. C is a coefficient which depends upon the height and form of the weir, whether or not there be end contractions, the character of the weir surface and the condition of the water on the downstream side. In weir formulas it is customary to combine one or more of the factors $\frac{2}{3}$, C, and $2g$ into a single coefficient.

Four Recognized Formulas for the discharge of weirs are as follows, but the first and the fourth are the most important.

The Francis Formula

$$Q = 3.33\ LH^{3/2} \text{ or } Q = 3.33\ L[(h+hv)^{3/2} - hv^{3/2}]$$

The Fteley and Stearns Formula

$$Q = 3.31\ LH^{3/2} + 0.007L \text{ or } Q = 3.31L(h+1.5hv)^{3/2} + 0.007L$$

The Hamilton Smith Formula

$Q = 3.29(L + H/7)H^{3/2}$ or

$$Q = 3.29\left(L + \frac{h + 1\frac{1}{3}hv}{7}\right)(h + 1\frac{1}{3}hv)^{3/2}$$

The Bazin Formula

$Q = mLh\sqrt{2gh}$, where

$$m = \left(0.405 + \frac{0.00984}{h}\right)\left[1 + 0.55\left(\frac{h}{a+h}\right)^2\right]$$

in which a is the height of the crest of the weir above the bottom of the channel of approach. For weirs with end contractions, Francis concluded that L in the above formulas should be replaced by $L - 0.1nH$, where n is the number of full end contractions. This correction has been generally accepted, but it is by no means accurate, and for exact work in measuring water a weir without end contractions is to be preferred. These formulas all apply to a weir with a vertical upstream face, a sharp edge and with free access of air to the under side of the overfalling sheet of water.

Triangular or V-shaped Weir. This form of weir, suggested by Prof. Thomson of Dublin, possesses the peculiarity that, whatever the heads, the sections of the stream are similar, and hence it may be expected to have a coefficient more nearly constant than the ordinary weir and be particularly well adapted to the measurement of water where the flow varies through a considerable range. The coefficient will vary for different inclinations of the sides of the notch. For a sharp-edged weir in which the sides make an angle of 90° with each other, since $L = 2h$, the discharge is $Q = 2.6h^{5/2}$.

No experiments have been made upon weirs of this type when other than sharp edged with vertical faces, but the effects of inclination and rounding may be expected to affect them similarly to rectangular weirs.

Rounding the Upstream Corner of the crest of a weir increases the discharge. With flat-crested weirs Bazin found this effect to amount to as much as 13% where the radius of

the rounding was 4 inches and the breadth of crest 6.56 feet. Fteley and Stearns, with weirs up to one inch in breadth, found the rounding to be equivalent to increasing the head by $h_R = 0.7R$, where R is the radius of the rounding.

Inclining the Upstream Face away from the current decreases the contraction and increases the discharge as much as 10% when the slope is one of 45°. If the inclination be in the opposite direction, the contraction is increased and the discharge decreased. With a 45° slope, the decrease may be as much as 7%. Inclining the ***Down Stream Face*** does not materially alter the discharge until the slope becomes at least 3 horizontal to 1 vertical, when the discharge is reduced.

Rounding the Entire Crest reduces the discharge for low heads, but increases it for those wherein the curve of the crest approaches the curve of the natural under side of the sheet. By a combination of a rounded crest and an inclined upstream slope, the discharge may be increased 20% above that of the sharp-edged weir.

Flat Crests decrease the discharge until the head becomes so high that the sheet jumps clear of the downstream corner, when they have no effect. A broad flat crest may reduce the discharge 25% below that of the sharp edge.

The Sheet of Water adhering to the downstream face of a vertical sharp-edged weir has increased the discharge about 28%. The sheet being wetted, that is depressed and the space between it and the weir filled with water, due to the formation there of a partial vacuum, has increased the discharge about 15%. The sheet being depressed, but the space only partially filled with water, has increased the discharge about 6%.

Submerged Weirs. When water on the downstream side of the weir rises above the level of the crest, the weir is said to be submerged. If h_u is the head observed on the upstream side and h is the difference of head on the two sides, the usual formula for the discharge of a submerged weir is

$$Q = CL\sqrt{2gh}(hu - h/3)$$

where C for a sharp edge varies from 0.58 to 0.63. On account of the difficulty of measuring hl, the head in the lower pool,

because of the turbulence there, accurate results with this formula are impossible. Experiment shows that so long as the water flowing over the weir plunges to the bottom of the channel below or dives under that in the lower pool, the discharge of the weir is not decreased more than 10% by the submergence. In rounded weirs it is possible to submerge the crests to fully 30% of *hu* without varying the discharge from that for a free weir under the head *hu* more than the above percent; and for submergence of less than 10% of *hu* the discharge is likely to be increased by the exclusion of air behind the sheet.

The Weir affords the most commonly used method of measuring water in moderately large quantities. The standard weir, or sharp-edged weir, consists of a vertical partition across a channel with its top edge horizontal, sharp cornered and narrow enough so that at the heads used the overflowing sheet jumps from the upstream edge clear of the downstream corner. Such weirs may be either with or without end contractions. A weir with end contractions is one whose crest extends only part way across the channel and is terminated by partitions in its plane, with their vertical edges rising above the level of the water on the upstream side. Such a weir may be compared to a rectangular orifice upon which the head has fallen below the top. A weir without end contractions is one which extends entirely across the channel. If a = height of crest of weir above bottom of channel of approach, A_w = area of stream in the plane of the weir, H = height above the crest of the surface of still water upstream from the weir, h = head above crest as observed, v_w = velocity in and perpendicular to the plane of the weir, then the formula for the discharge is similar to that for the orifice and is

$$Q = A_w v_w = \tfrac{2}{3} CL\sqrt{2g}\, H^{3/2} = \tfrac{2}{3} CL\sqrt{2g}(h+hv)^{3/2}.$$

Since $LH = L(h+hv)$ = area of the stream above the crest level at the plane of still water and CLH is the area in the plane of the crest, the total head producing flow is $\tfrac{2}{3}\sqrt{2g(h+hv)}$.

The Francis Formula. The coefficient C in this formula was determined experimentally by James B. Francis as about 0.62, and by combining this with, $\tfrac{2}{3}\sqrt{2g}$, the well-known co-

efficient of the Francis Formula 3.33 is obtained. This formula was considered by its inventor to be reliable between heads of 0.5 foot and 2.00 feet. Later investigators have modified it into the form:

$$Q = 3.33L(h + 1.4hv)^{3/2}$$

In applying this formula the process is as follows: Having measured the head h at a point above the surface curve to the weir, compute an approximate value of the discharge by the equation $Q_1 = 3.33Lh^{3/2}$. Find the approximate velocity at the plane where the head is observed by the equation $v = Q_1 \div L(h+a)$ and the velocity head by $h = v^{3/2}g$. Then Q is obtained by substitution in the above formula, and should be within 3 to 4 percent of correctness if the head is not more than 30 percent of a and has been properly measured, and the sheet is fully aerated underneath.

For weirs with end contractions Francis recommended reducing the length L in the above formula by 0.1 H for each full end contraction. This correction is only an approximation and, for accurate gagings, weirs with end contractions should not be used.

The Bazin Formula is the most accurate one for wide ranges of head, and it may be safely applied between heads of 0.2 foot and 6 feet, and does not require a correction for velocity of approach, as it is based upon the observed head h. It applies only to weirs without end contractions and is

$$Q = \left(0.405 + \frac{0.00984}{h}\right)\left[1 + 0.55\left(\frac{h}{a+h}\right)^2\right] Lh\sqrt{2gh}$$

and the following tables give values of Q for a weir one foot long and for various values of h and a. The value of g used in computing these tables is 32.17 feet per second.

Discharge in Cubic Feet per Second per Foot of Length over Sharp-edged Vertical Weirs Without End Contractions

Computed by Bazin's Formula

Head h feet	Height in feet of crest of weir above bottom of channel of approach						
	$a=2$	$a=3$	$a=4$	$a=5$	$a=6$	$a=7$	$a=8$
0.2	0.33	0.33	0.33	0.33	0.33	0.33	0.33
0.3	0.58	0.58	0.58	0.58	0.58	0.58	0.58
0.4	0.88	0.88	0.88	0.87	0.87	0.87	0.87
0.5	1.23	1.21	1.21	1.21	1.21	1.21	1.21
0.6	1.62	1.59	1.59	1.58	1.58	1.58	1.58
0.7	2.04	2.01	1.99	1.98	1.98	1.98	1.98
0.8	2.50	2.45	2.43	2.42	2.41	2.41	2.41
0.9	3.00	2.93	2.90	2.88	2.88	2.87	2.86
1.0	3.53	3.44	3.40	3.38	3.36	3.36	3.35
1.2	4.68	4.55	4.48	4.47	4.42	4.41	4.40
1.4	5.99	5.78	5.68	5.62	5.58	5.56	5.54
1.5	6.68	6.44	6.30	6.23	6.20	6.18	6.16
1.6	7.40	7.12	6.97	6.89	6.84	6.80	6.78
1.8	8.93	8.56	8.37	8.25	8.18	8.13	8.09
2.0	10.58	10.12	9.87	9.72	9.62	9.55	9.51
2.2	12.34	11.77	11.46	11.27	11.14	11.06	10.99
2.4	14.20	13.53	13.15	12.91	12.75	12.64	12.56
2.5	15.17	14.45	14.03	13.76	13.59	13.47	13.38
2.6	16.16	15.38	14.92	14.63	14.44	14.30	14.20
2.8	18.23	17.32	16.79	16.44	16.21	16.04	15.92
3.0	20.39	19.36	18.74	18.33	18.06	17.86	17.71
3.2	22.64	21.48	20.77	20.31	19.98	19.75	19.58
3.4	24.98	23.70	22.89	22.36	21.99	21.72	21.52
3.5	26.20	24.83	24.00	23.43	23.01	22.73	22.48
3.6	27.41	25.99	25.09	24.49	24.06	23.75	23.52
3.8	29.94	28.38	27.38	26.70	26.22	25.87	25.60
4.0	32.54	30.84	29.74	28.99	28.45	28.05	27.74
4.2	35.22	33.39	32.18	31.35	30.75	30.30	29.96
4.4	37.99	36.01	34.70	33.78	33.12	32.62	32.24
4.6	40.83	38.71	37.29	36.29	35.56	35.01	34.58
4.8	43.75	41.49	39.96	38.87	38.07	37.46	37.00
5.0	46.71	44.31	42.67	41.49	40.62	39.96	39.44
5.2	49.81	47.27	45.50	44.23	43.29	42.57	42.01
5.4	52.94	50.23	48.38	47.02	46.00	45.22	44.60
5.6	56.15	53.33	51.34	49.88	48.79	47.94	47.28
5.8	59.42	56.45	54.34	52.79	51.62	50.71	49.99
6.0	62.77	59.65	56.43	55.78	54.53	53.55	52.78

Discharge in Cubic Feet per Second per Foot of Length over Sharp-edged Vertical Weirs Without End Contractions—Continued

Computed by Bazin's Formula

Head h feet	Height in feet of crest of weir above bottom of channel of approach						
	$a=9$	$a=10$	$a=12$	$a=16$	$a=20$	$a=25$	$a=30$
0.2	0.33	0.33	0.33	0.33	0.33	0.33	0.33
0.3	0.58	0.58	0.58	0.58	0.58	0.58	0.58
0.4	0.87	0.87	0.87	0.87	0.87	0.87	0.87
0.5	1.21	1.21	1.21	1.21	1.20	1.20	1.20
0.6	1.57	1.57	1.57	1.57	1.57	1.57	1.57
0.7	1.97	1.97	1.97	1.97	1.97	1.97	1.97
0.8	2.40	2.40	2.40	2.40	2.40	2.40	2.40
0.9	2.86	2.86	2.86	2.86	2.85	2.85	2.85
1.0	3.35	3.34	3.34	3.33	3.33	3.33	3.33
1.2	4.39	4.38	4.38	4.37	4.36	4.36	4.36
1.4	5.53	5.52	5.51	5.49	5.49	5.48	5.48
1.5	6.14	6.13	6.12	6.11	6.10	6.09	6.09
1.6	6.76	6.74	6.73	6.71	6.69	6.69	6.69
1.8	8.07	8.05	8.02	7.99	7.98	7.97	7.96
2.0	9.47	9.44	9.40	9.36	9.34	9.33	9.32
2.2	10.95	10.91	10.86	10.81	10.78	10.76	10.75
2.4	12.50	12.45	12.39	12.32	12.28	12.25	12.24
2.5	13.31	13.26	13.18	13.10	13.06	13.03	13.01
2.6	14.13	14.07	13.99	13.90	13.85	13.82	13.80
2.8	15.83	15.76	15.66	15.54	15.48	15.44	15.42
3.0	17.60	17.52	17.39	17.25	17.18	17.13	17.10
3.2	19.45	19.34	19.19	19.02	18.93	18.87	18.83
3.4	21.36	21.24	21.06	20.86	20.75	20.68	20.63
3.5	22.38	22.22	22.00	21.83	21.69	21.62	21.60
3.6	23.34	23.20	22.99	22.75	22.62	22.53	22.48
3.8	25.39	25.23	24.99	24.71	24.56	24.45	24.39
4.0	27.51	27.32	27.05	26.72	26.55	26.42	26.35
4.2	29.69	29.48	29.17	28.79	28.59	28.45	28.36
4.4	31.94	31.70	31.34	30.92	30.66	30.52	30.42
4.6	34.25	33.98	33.58	33.10	32.84	32.65	32.53
4.8	36.62	36.33	35.88	35.35	35.05	34.83	34.70
5.0	39.03	38.70	38.21	37.61	37.28	37.03	36.88
5.2	41.56	41.20	40.65	39.99	39.61	39.33	39.17
5.4	44.11	43.71	43.12	42.38	41.96	41.66	41.47
5.6	46.74	46.31	45.65	44.84	44.38	44.04	43.83
5.8	49.41	48.94	48.22	47.33	46.83	46.45	46.22
6.0	52.15	51.64	50.86	49.90	49.34	48.92	48.67

When the weir is so high that the velocity of the approaching water is practically zero Bazin's formula reduces to

$$Q=\left(0.405+\frac{0.00984}{h}\right)Lh\sqrt{2gh}$$

At low heads, less than 0.2 of a foot, Bazin's Formula gives discharges somewhat too high and the formula proposed by Fteley and Stearns is recommended, which is:

$$Q=3.33LH^{3/2}+0.0065L.$$

The results by this formula are within 4 to 6 per cent of the experimental values for heads ranging from 0.2 to 0.007 ft., and the actual discharges were generally in excess of those given by the formula. It holds only so long as the sheet jumps free of the crest and the space behind it is fully aerated.

The Flow Over the Irregular Crests may be computed by multiplying the discharge of a standard weir of the same height and length and at the same head by a factor depending on the form of the crests. The following tables give the multipliers for various forms of weirs as determined from experiments upon full-size models at the Hydraulic Laboratory of Cornell University:

Multipliers for Flat-topped Weirs.

Head h, feet	Width of flat crest in feet							
	$b=$ 0.48	$b=$ 0.93	$b=$ 1.65	$b=$ 3.17	$b=$ 5.84	$b=$ 8.98	$b=$ 12.24	$b=$ 16.30
0.5	0.902	0.830	0.819	0.797	0.785	0.783	0.783	0.783
1.0	0.972	0.904	0.879	0.812	0.800	0.798	0.795	0.792
1.5	1.000	0.957	0.910	0.821	0.807	0.803	0.802	0.797
2.0	1.000	0.989	0.925	0.821	0.805	0.800	0.798	0.795
2.5	1.000	1.000	0.932	0.816	0.800	0.795	0.792	0.789
3.0	1 000	1.000	0.938	0.813	0.796	0.791	0.787	0.784
3.5	1.000	1.000	0.942	0.810	0.793	0.787	0.783	0.780
4.0	1.000	1.000	0.947	0.808	0.790	0.783	0.780	0.777

Multipliers (m) for Triangular Weirs.

Head h in feet,	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0
For $b=$ 6.65 ft., $m=$	1.060	1.079	1.091	1.086	1.076	1.067	1.060	1.054
For $b=$ 11.25 ft., $m=$	1.060	1.079	1.092	1.097	1.096	1.095	1.094	1.093

Water Power

From Kent's Mechanical Engineers' Pocket Book

Power of a Fall of Water—Efficiency. The gross power of a fall of water is the product of the weight of water discharged in a unit of time into the total head, i. e., the difference of vertical elevation of the upper surface of the water at the points where the fall in question begins and ends. The

term "head" used in connection with water-wheels is the difference in height from the surface of the water in the wheel-pit to the surface in the penstock when the wheel is running.

If Q = cubic feet of water discharged per second, D = weight of a cubic foot of water = 62.36 pounds at 60° F., H = total head in feet; then

DQH = gross power in foot pounds per second,

and

$DQH \div 550 = 0.1134QH$ = gross horse-power.

Q' is taken in cubic feet per minute.

$$\text{H.P.} = \frac{Q'H \times 62.36}{33000} = .00189Q'H.$$

A water-wheel or motor of any kind cannot utilize the whole of the head H, since there are losses of head at both the entrance to and the exit from the wheel. There are also losses of energy due to friction of the water in its passage through the wheel. The ratio of the power developed by the wheel to the gross power of the fall is the efficiency of the wheel. For 75% efficiency, net horse-power $= 0.00142\,Q'H = \frac{Q'H}{706}$.

A head of water can be made use of in one or other of the following ways, viz:

First. By its weight, as in the water-balance and in the overshot wheel.

Second. By its pressure, as in turbines and in the hydraulic engine, hydraulic press, crane, etc.

Third. By its impulse, as in the undershot wheel, and in the Pelton wheel.

Fourth. By a combination of the above.

Horse-power of a Running Stream. The gross horse-power is $\text{H.P.} = QH \times 62.36 \div 550 = 0.1134QH$, in which Q is the discharge in cubic feet per second actually impinging on the float or bucket, and H = theoretical head due to the velocity of the stream $= \frac{v^2}{2g} = \frac{v^2}{64.4}$, in which v is the velocity in feet per second. If Q' be taken in cubic feet per minute $\text{H.P.} = 0.00189\,Q'H$.

Thus, if the floats of an undershot wheel driven by a current alone be 5 feet × 1 foot, and the velocity of the stream = 210 feet per minute, or 3½ feet per second, of which the theoretical head is 0.19 feet, $Q = 5$ square feet × 210 = 1050 cubic feet per minute; H. P. = 1050 × 0.19 × 0.00189 = 0.377 H. P.

The wheels would realize only about 0.4 of this power on account of friction and slip, or 0.151 H. P., or about 0.03 H. P. per square foot of float, which is equivalent to 33 square feet of float per H. P.

Current Motors. A current motor could only utilize the whole power of a running stream if it could take all the velocity out of the water, so that it would leave the floats or buckets with no velocity at all; or in other words, it would require the backing up of the whole volume of the stream until the actual head was equivalent to the theoretical head due to the velocity of the stream. As but a small fraction of the velocity of the stream can be taken up by a current motor, its efficiency is very small. Current motors may be used to obtain small amounts of power from large streams, but for large powers they are not practicable.

Bernoulli's Theorem. Energy of Water Flowing in a Tube

The head due to the velocity is $\frac{v^2}{2g}$; the head due to the pressure is $\frac{f}{w}$; the head due to actual height above the datum plane is h feet. The total head is the sum of these $= \frac{v^2}{2g} + h + \frac{f}{w}$, in feet, in which v = velocity in feet per second, f = pressure in pounds per square foot, w = weight of 1 cubic foot of water = 62.36 pounds. If p = pressure in pounds per square inch $\frac{f}{w} = 2.309p$. If a constant quantity of water is flowing through a tube in a given time, the velocity varying at different points on account of changes in the diameter, the energy remains constant (loss by friction excepted) and the sum of the three heads is constant, the pressure head increasing as the velocity de-

creases, and vice versa. This principle is known as "Bernoulli's Theorem."

In hydraulic transmission the velocity and the height above datum are usually small compared with the pressure head. The work or energy of a given quantity of water under pressure = its volume in cubic feet $\times$ its pressure in pounds per square foot; or if Q = quantity in cubic feet per second, and p = pressure in pounds per square inch, $W = 144\ pQ$ and the H. P. $= \frac{144pQ}{550} = 0.2618\ pQ$.

Flow of Water in Pipes

Water is composed of two gases, hydrogen and oxygen, in the ratio of two volumes of the former to one of the latter. It is never found pure in nature, owing to the readiness with which it absorbs impurities from the air and soil. Water boils under atmospheric pressure (14.7 pounds at sea level) at 212°, passing off as steam. Its greatest density is at 39.1° F., when it weighs 62.425 pounds per cubic foot.

Compressibility of Water. Water is very slightly compressible. Its compressibility is from 0.000040 to 0.000051 for one atmosphere, decreasing with increase of temperature. For each foot of pressure, distilled water will be diminished in volume 0.0000015 to 0.0000013. Water is so incompressible that even at a depth of a mile a cubic foot of water will weigh only about half a pound more than at the surface.

Table for Calculating the Horse-power of Water Heads

(Pelton Water Wheel Company.)

The following table gives the horse-power of 1 cubic foot of water per minute under heads from 1 up to 2100 feet.

H'ds in ft.	Horse-power	H'ds in ft.	Horse-power	Heads in feet	Horse-power	Heads in feet	Horse-power
1	.0016098	220	.354156	430	.692214	1050	1.690290
20	.032196	230	.370254	440	.708312	1100	1.770780
30	.048294	240	.386352	450	.724410	1150	1.851270
40	.064392	250	.402450	460	.740508	1200	1.931760
50	.080490	260	.418548	470	.756606	1250	2.012250
60	.096588	270	.434646	480	.772704	1300	2.092740
70	.112686	280	.450744	490	.788802	1350	2.173230
80	.128784	290	.466842	500	.804900	1400	2.253720
90	.144882	300	.482940	520	.837096	1450	2.334210
100	.160980	310	.499038	540	.869292	1500	2.414700
110	.177078	320	.515136	560	.901488	1550	2.495190
120	.193176	330	.531234	580	.933684	1600	2.575680
130	.209274	340	.547332	600	.965880	1650	2.656170
140	.225372	350	.563430	650	1.046370	1700	2.736660
150	.241470	360	.579528	700	1.126860	1750	2.817150
160	.257568	370	.595626	750	1.207350	1800	2.897640
170	.273666	380	.611724	800	1.287840	1850	2.978130
180	.289764	390	.627822	850	1.368330	1900	3.058620
190	.305862	400	.643920	900	1.448820	1950	3.139110
200	.321960	410	.660018	950	1.529310	2000	3.219600
210	.338058	420	.676116	1000	1.609800	2100	3.380580

When the Exact Head is Found in Above Table

Example: Have 100-foot head and 50 cubic feet of water per minute. How many horse-power?

By reference to the above table the horse-power of each cubic foot under 100-foot head will be found to be .16098. This amount multiplied by the number of cubic feet per minute, 50, will give 8.05 horse-power.

When Exact Head is Not Found in Table

Take the horse-power of 1 cubic foot per minute under 1-foot head, and multiply by the number of cubic feet available, and then by the number of feet head. The product will be the required horse-power.

Note: The above table is based upon an efficiency of 85 per cent.

Slope Reduction Tables

Elevation Feet	Slope Distances in Feet										Elevation Feet
	10	20	30	40	50	60	70	80	90	100	
0.0											0.0
.1	.001										.1
.2	.002	.001	.001	.001							.2
.3	.005	.002	.002	.001	.001	.001	.001	.001	.001	.001	.3
.4	.008	.004	.003	.002	.001	.001	.001	.001	.001	.001	.4
0.5	.013	.006	.004	.003	.003	.002	.002	.002	.001	.001	0.5
.6	.018	.009	.006	.005	.004	.003	.003	.002	.002	.002	.6
.7	.025	.012	.008	.006	.005	.004	.004	.003	.003	.003	.7
.8	.032	.016	.011	.008	.006	.005	.005	.004	.004	.003	.8
.9	.041	.020	.014	.010	.008	.007	.006	.005	.005	.004	.9
1.0	.050	.025	.017	.013	.010	.008	.007	.006	.006	.005	1.0
.1	.061	.030	.020	.015	.012	.010	.008	.008	.007	.006	.1
.2	.072	.036	.024	.018	.014	.012	.010	.009	.008	.007	.2
.3	.085	.042	.028	.021	.017	.014	.012	.011	.009	.009	.3
.4	.099	.049	.033	.025	.020	.016	.014	.012	.011	.010	.4
1.5	.113	.056	.038	.028	.023	.019	.016	.014	.013	.011	1.5
.6	.129	.064	.043	.032	.026	.021	.018	.016	.014	.013	.6
.7	.146	.072	.048	.036	.029	.024	.021	.018	.016	.015	.7
.8	.163	.081	.054	.041	.032	.027	.023	.020	.018	.016	.8
.9	.182	.090	.060	.045	.036	.030	.026	.023	.020	.018	.9
2.0	.202	.100	.067	.050	.040	.033	.029	.025	.022	.020	2.0
.1	.223	.111	.074	.055	.044	.037	.032	.028	.025	.022	.1
.2	.245	.121	.081	.061	.048	.040	.035	.030	.027	.024	.2
.3	.268	.133	.088	.066	.053	.044	.038	.033	.029	.027	.3
.4	.292	.145	.096	.072	.058	.048	.041	.036	.032	.029	.4
2.5	.317	.157	.104	.078	.063	.052	.045	.039	.035	.031	2.5
.6	.344	.170	.113	.085	.068	.056	.048	.042	.038	.034	.6
.7	.371	.183	.122	.091	.073	.061	.052	.046	.041	.037	.7
.8	.400	.197	.131	.098	.079	.065	.056	.049	.044	.039	.8
.9	.429	.211	.141	.105	.086	.070	.060	.053	.047	.042	.9
3.0	.460	.226	.150	.113	.090	.075	.064	.056	.050	.045	3.0
.1	.493	.242	.161	.120	.096	.080	.069	.060	.053	.048	.1
.2	.526	.258	.171	.128	.103	.085	.073	.064	.057	.051	.2
.3	.560	.274	.182	.136	.109	.091	.078	.068	.061	.055	.3
.4	.596	.291	.193	.145	.116	.096	.083	.072	.064	.058	.4
3.5	.633	.309	.205	.153	.123	.102	.088	.077	.068	.061	3.5
.6	.671	.327	.217	.162	.130	.108	.093	.081	.072	.065	.6
.7	.710	.345	.229	.172	.137	.114	.098	.085	.076	.069	.7
.8	.750	.364	.242	.181	.145	.120	.103	.090	.080	.072	.8
.9	.792	.384	.255	.191	.152	.127	.109	.095	.085	.076	.9
4.0	.835	.404	.268	.201	.160	.133	.114	.100	.089	.080	4.0

EXAMPLE—Given a slope measurement of 80 feet, with a difference of level of 2.1 feet, to ascertain the horizontal distance:—From the table under 80 and opposite 2.1, find .028 feet, the correction to be deducted; then 80.00—.028—79.972 feet, the correct horizontal distance.

Slope Reduction Tables

Elevation Feet	Slope Distances in Feet										Elevation Feet
	10	20	30	40	50	60	70	80	90	100	
4.1	.879	.425	.282	.211	.168	.140	.120	.105	.093	.084	4.1
.2	.925	.446	.295	.221	.177	.147	.126	.110	.098	.088	.2
.3	.972	.468	.310	.232	.185	.154	.132	.116	.103	.092	.3
.4	1.020	.490	.324	.243	.194	.162	.138	.121	.108	.097	.4
4.5	1.070	.513	.339	.254	.203	.169	.145	.127	.113	.101	4.5
.6	1.121	.536	.355	.265	.212	.176	.151	.132	.118	.106	.6
.7	1.173	.560	.370	.277	.222	.184	.158	.138	.123	.111	.7
.8	1.227	.584	.387	.289	.231	.192	.165	.144	.128	.115	.8
.9	1.283	.609	.403	.301	.241	.200	.172	.150	.134	.120	.9
5.0	1.340	.635	.420	.314	.251	.209	.179	.157	.139	.125	5.0
.1	1.398	.661	.437	.326	.261	.217	.186	.163	.145	.130	.1
.2	1.458	.688	.454	.339	.271	.226	.193	.169	.150	.135	.2
.3	1.520	.715	.472	.353	.282	.235	.201	.176	.156	.141	.3
.4	1.583	.743	.490	.366	.293	.244	.209	.183	.162	.146	.4
5.5	1.648	.771	.508	.380	.303	.253	.216	.189	.168	.151	5.5
.6	1.715	.800	.527	.394	.314	.262	.224	.196	.174	.157	.6
.7	1.784	.829	.546	.408	.326	.271	.233	.203	.181	.163	.7
.8	1.854	.859	.566	.423	.338	.281	.241	.211	.187	.168	.8
.9	1.926	.890	.586	.438	.349	.291	.249	.218	.194	.174	.9
6.0	2.000	.921	.606	.453	.361	.301	.258	.225	.200	.180	6.0
.1	2.076	.953	.627	.468	.374	.311	.266	.233	.207	.186	.1
.2	2.154	.985	.648	.483	.386	.321	.275	.241	.214	.192	.2
.3	2.234	1.018	.669	.499	.399	.332	.284	.249	.221	.199	.3
.4	2.316	1.052	.690	.515	.411	.342	.293	.256	.228	.205	.4
6.5	2.400	1.086	.713	.532	.424	.353	.303	.265	.235	.212	6.5
.6	2.487	1.120	.735	.548	.438	.364	.312	.273	.242	.218	.6
.7	2.576	1.155	.758	.565	.451	.375	.321	.281	.250	.225	.7
.8	2.668	1.191	.781	.582	.465	.386	.331	.290	.257	.232	.8
.9	2.762	1.228	.806	.600	.478	.398	.341	.298	.265	.238	.9
7.0	2.869	1.265	.828	.617	.492	.410	.351	.307	.273	.245	7.0
.1	2.968	1.302	.852	.635	.507	.422	.361	.316	.281	.252	.1
.2	3.060	1.341	.877	.653	.521	.434	.371	.325	.289	.266	.2
.3	3.166	1.380	.902	.672	.536	.446	.382	.334	.297	.267	.3
.4	3.274	1.419	.927	.690	.551	.458	.392	.343	.305	.274	.4
7.5	3.386	1.459	.953	.709	.566	.471	.403	.352	.313	.282	7.5
.6	3.511	1.500	.979	.729	.581	.483	.414	.362	.322	.289	.6
.7	3.620	1.542	1.005	.748	.596	.496	.425	.372	.330	.297	.7
.8	3.742	1.584	1.032	.768	.612	.509	.436	.381	.339	.305	.8
.9	3.869	1.626	1.059	.788	.628	.522	.447	.391	.347	.313	.9
8.0	4.000	1.670	1.086	.808	.644	.536	.459	.401	.356	.321	8.0

Slope Reduction Tables

Elevation Feet	Slope Distances in Feet										Elevation Feet
	10	20	30	40	50	60	70	80	90	100	
8.1	4.136	1.714	1.114	.829	.660	.549	.470	.411	.365	.329	.1
.2	4.276	1.758	1.142	.850	.677	.563	.482	.421	.374	.337	.2
.3	4.422	1.803	1.171	.871	.694	.577	.494	.432	.384	.345	.3
.4	4.574	1.849	1.200	.892	.711	.591	.506	.442	.393	.353	.4
8.5	4.732	1.896	1.229	.913	.728	.605	.518	.453	.402	.362	8.5
.6	4.897	1.943	1.259	.935	.745	.620	.530	.464	.412	.371	.6
.7	5.069	1.991	1.289	.958	.763	.634	.543	.475	.422	.379	.7
.8	5.250	2.040	1.320	.980	.780	.649	.555	.486	.431	.388	.8
.9	5.440	2.089	1.351	1.003	.798	.664	.568	.497	.441	.397	.9
9.0	5.641	2.139	1.382	1.026	.817	.679	.581	.508	.451	.406	9.0
.1	5.854	2.190	1.413	1.049	.835	.694	.594	.519	.461	.415	.1
.2	6.081	2.242	1.445	1.072	.854	.710	.607	.531	.471	.424	.2
.3	6.324	2.294	1.478	1.096	.872	.725	.621	.542	.482	.433	.3
.4	6.588	2.347	1.511	1.120	.891	.741	.634	.554	.492	.443	.4
9.5	6.877	2.400	1.544	1.144	.911	.757	.648	.566	.503	.452	9.5
.6	7.200	2.455	1.577	1.169	.930	.773	.661	.578	.514	.462	.6
.7	7.569	2.510	1.611	1.194	.950	.789	.675	.590	.524	.472	.7
.8	8.010	2.565	1.646	1.219	.970	.806	.689	.603	.535	.481	.8
.9	8.589	2.622	1.681	1.244	.990	.822	.704	.615	.546	.491	.9
10.0	10.000	2.679	1.716	1.270	1.010	.839	.718	.627	.557	.501	10.0
.1	.....	.....	1.751	1.296	1.031	.856	.733	.640	.569	.511	.1
.2	.....	.....	1.787	1.322	1.051	.873	.747	.653	.580	.521	.2
.3	.....	.....	1.823	1.349	1.072	.891	.762	.666	.591	.532	.3
.4	.....	.....	1.860	1.375	1.094	.908	.777	.679	.602	.542	.4
10.5	.....	.....	1.897	1.402	1.115	.926	.792	.692	.614	.553	10.5
.6	.....	.....	1.935	1.430	1.136	.944	.807	.705	.626	.563	.6
.7	.....	.....	1.973	1.458	1.158	.962	.823	.719	.638	.574	.7
.8	.....	.....	2.012	1.486	1.180	.980	.838	.732	.650	.585	.8
.9	.....	.....	2.051	1.514	1.202	.998	.854	.746	.663	.596	.9
11.0	.....	.....	2.089	1.542	1.225	1.017	.870	.760	.675	.607	11.0
.1	.....	.....	2.129	1.571	1.248	1.036	.886	.774	.687	.618	.1
.2	.....	.....	2.169	1.600	1.271	1.055	.902	.788	.700	.629	.2
.3	.....	.....	2.209	1.629	1.294	1.074	.918	.802	.712	.640	.3
.4	.....	.....	2.250	1.659	1.317	1.093	.935	.816	.725	.652	.4
11.5	.....	.....	2.292	1.689	1.340	1.112	.951	.831	.738	.663	11.5
.6	.....	.....	2.333	1.719	1.364	1.132	.968	.845	.751	.675	.6
.7	.....	.....	2.375	1.749	1.388	1.152	.985	.860	.764	.687	.7
.8	.....	.....	2.418	1.780	1.412	1.172	1.002	.875	.777	.699	.8
.9	.....	.....	2.461	1.811	1.437	1.192	1.019	.890	.790	.711	.9
12.0	.....	.....	2.505	1.842	1.461	1.212	1.036	.905	.804	.723	12.0

Slope Reduction Tables

Elevation Feet	Slope Distances in Feet										Elevation Feet
	10	20	30	40	50	60	70	80	90	100	
12.1	.....	.....	2.548	1.874	1.486	1.232	1.054	.920	.817	.735	12.1
.2	.....	.....	2.593	1.906	1.511	1.253	1.071	.936	.831	.747	.2
.3	.....	.....	2.637	1.938	1.536	1.274	1.089	.951	.844	.759	.3
.4	.....	.....	2.683	1.971	1.562	1.295	1.107	.967	.858	.772	.4
12.5	.....	.....	2.728	2.003	1.588	1.316	1.125	.983	.872	.784	12.5
.6	.....	.....	2.774	2.036	1.614	1.338	1.143	.999	.886	.797	.6
.7	.....	.....	2.821	2.070	1.640	1.359	1.162	1.015	.901	.810	.7
.8	.....	.....	2.867	2.103	1.666	1.381	1.180	1.031	.915	.823	.8
.9	.....	.....	2.915	2.137	1.693	1.403	1.199	1.047	.929	.836	.9
13.0	.....	.....	2.963	2.171	1.720	1.425	1.218	1.063	.944	.849	13.0
.1	.....	.....	3.011	2.206	1.747	1.448	1.237	1.080	.959	.862	.1
.2	.....	.....	3.060	2.241	1.774	1.470	1.256	1.097	.973	.875	.2
.3	.....	.....	3.109	2.276	1.801	1.492	1.275	1.113	.988	.888	.3
.4	.....	.....	3.159	2.311	1.829	1.515	1.294	1.130	1.003	.902	.4
13.5	.....	.....	3.209	2.347	1.857	1.538	1.314	1.147	1.018	.915	13.5
.6	.....	.....	3.260	2.383	1.885	1.561	1.334	1.164	1.034	.929	.6
.7	.....	.....	3.311	2.419	1.914	1.585	1.354	1.182	1.049	.943	.7
.8	.....	.....	3.362	2.456	1.942	1.608	1.374	1.199	1.064	.957	.8
.9	.....	.....	3.414	2.493	1.971	1.632	1.394	1.217	1.080	.971	.9
14.0	.....	.....	3.467	2.530	2.000	1.656	1.414	1.235	1.096	.985	14.0
.1	.....	.....	3.520	2.567	2.029	1.680	1.435	1.252	1.111	.999	.1
.2	.....	.....	3.573	2.605	2.059	1.704	1.455	1.270	1.127	1.013	.2
.3	.....	.....	3.627	2.643	2.089	1.729	1.476	1.288	1.143	1.028	.3
.4	.....	.....	3.682	2.682	2.119	1.754	1.497	1.307	1.159	1.042	.4
14.5	.....	.....	3.737	2.721	2.149	1.778	1.518	1.325	1.176	1.057	14.5
.6	.....	.....	3.792	2.760	2.179	1.803	1.539	1.344	1.192	1.072	.6
.7	.....	.....	3.848	2.799	2.210	1.829	1.561	1.362	1.209	1.086	.7
.8	.....	.....	3.904	2.839	2.241	1.854	1.592	1.381	1.225	1.101	.8
.9	.....	.....	3.961	2.879	2.272	1.879	1.604	1.400	1.242	1.116	.9
15.0	.....	.....	4.019	2.919	2.303	1.905	1.626	1.419	1.259	1.131	15.0
.1	.....	.....	.....	2.960	2.335	1.931	1.648	1.438	1.276	1.147	.1
.2	.....	.....	.....	3.001	2.366	1.957	1.670	1.457	1.293	1.162	.2
.3	.....	.....	.....	3.042	2.398	1.983	1.692	1.477	1.310	1.177	.3
.4	.....	.....	.....	3.083	2.431	2.010	1.715	1.496	1.327	1.193	.4
15.5	.....	.....	.....	3.124	2.463	2.037	1.738	1.516	1.345	1.208	15.5
.6	.....	.....	.....	3.167	2.496	2.063	1.760	1.536	1.362	1.224	.6
.7	.....	.....	.....	3.210	2.529	2.090	1.783	1.556	1.380	1.240	.7
.8	.....	.....	.....	3.253	2.562	2.117	1.806	1.576	1.398	1.256	.8
.9	.....	.....	.....	3.296	2.596	2.145	1.830	1.596	1.416	1.272	.9
16.0	.....	.....	.....	3.339	2.629	2.173	1.853	1.616	1.434	1.288	16.0

Slope Reduction Tables

Elevation Feet	Slope Distances in Feet										Elevation Feet
	10	20	30	40	50	60	70	80	90	100	
16.1	.....	.....	.....	3.383	2.663	2.200	1.877	1.637	1.452	1.305	16.1
.2	.....	.....	.....	3.427	2.697	2.228	1.900	1.657	1.470	1.321	.2
.3	.....	.....	.....	3.472	2.732	2.256	1.924	1.678	1.488	1.337	.3
.4	.....	.....	.....	3.517	2.766	2.285	1.948	1.899	1.507	1.354	.4
16.5	.....	.....	.....	3.562	2.801	2.313	1.972	1.720	1.526	1.371	16.5
.6	.....	.....	.....	3.608	2.836	2.342	1.997	1.741	1.544	1.387	.6
.7	.....	.....	.....	3.653	2.871	2.371	2.021	1.762	1.563	1.404	.7
.8	.....	.....	.....	3.699	2.907	2.400	2.046	1.784	1.582	1.421	.8
.9	.....	.....	.....	3.746	2.943	2.429	2.071	1.805	1.601	1.438	.9
17.0	.....	.....	.....	3.792	2.979	2.459	2.096	1.827	1.620	1.456	17.0
.1	.....	.....	.....	3.839	3.015	2.488	2.121	1.849	1.639	1.473	.1
.2	.....	.....	.....	3.887	3.051	2.518	2.146	1.871	1.659	1.490	.2
.3	.....	.....	.....	3.935	3.088	2.548	2.171	1.893	1.678	1.508	.3
.4	.....	.....	.....	3.982	3.125	2.578	2.197	1.915	1.698	1.525	.4
17.5	.....	.....	.....	4.031	3.162	2.609	2.223	1.937	1.718	1.543	17.5
.6	.....	.....	.....	4.080	3.200	2.639	2.249	1.960	1.738	1.561	.6
.7	.....	.....	.....	4.129	3.238	2.670	2.275	1.983	1.758	1.579	.7
.8	.....	.....	.....	4.179	3.276	2.701	2.301	2.005	1.778	1.597	.8
.9	.....	.....	.....	4.229	3.314	2.732	2.327	2.028	1.798	1.615	.9
18.0	.....	.....	.....	4.279	3.352	2.764	2.354	2.051	1.818	1.633	18.0
.1	.....	.....	.....	4.329	3.391	2.795	2.381	2.074	1.839	1.652	.1
.2	.....	.....	.....	4.380	3.430	2.827	2.407	2.098	1.859	1.670	.2
.3	.....	.....	.....	4.432	3.469	2.859	2.434	2.122	1.880	1.689	.3
.4	.....	.....	.....	4.483	3.509	2.891	2.461	2.145	1.901	1.707	.4
18.5	.....	.....	.....	4.535	3.548	2.923	2.489	2.168	1.922	1.726	18.5
.6	.....	.....	.....	4.588	3.588	2.956	2.516	2.192	1.943	1.745	.6
.7	.....	.....	.....	4.640	3.628	2.988	2.544	2.216	1.964	1.764	.7
.8	.....	.....	.....	4.693	3.669	3.021	2.572	2.240	1.985	1.783	.8
.9	.....	.....	.....	4.747	3.710	3.054	2.600	2.265	2.007	1.802	.9
19.0	.....	.....	.....	4.801	3.751	3.088	2.628	2.289	2.028	1.822	19.0
.1	.....	.....	.....	4.855	3.792	3.121	2.656	2.314	2.050	1.841	.1
.2	.....	.....	.....	4.909	3.833	3.155	2.685	2.338	2.072	1.861	.2
.3	.....	.....	.....	4.964	3.875	3.189	2.713	2.363	2.094	1.880	.3
.4	.....	.....	.....	5.019	3.917	3.223	2.742	2.388	2.116	1.900	.4
19.5	.....	.....	.....	5.075	3.959	3.257	2.771	2.413	2.138	1.920	19.5
.6	.....	.....	.....	5.131	4.002	3.291	2.800	2.438	2.160	1.940	.6
.7	.....	.....	.....	5.187	4.045	3.326	2.829	2.463	2.182	1.960	.7
.8	.....	.....	.....	5.244	4.088	3.361	2.858	2.489	2.205	1.980	.8
.9	.....	.....	.....	5.301	4.131	3.396	2.888	2.514	2.227	2.000	.9
20.0	.....	.....	.....	5.359	4.174	3.431	2.918	2.540	2.250	2.020	20.0

Constants for Cut of 1 deg. for Different Diams.

Diam.	3/16" Pl.	1/4" Pl.	5/16" Pl.	3/8" Pl.	7/16" Pl.	1/2" Pl.
Inches	Inches	Inches	Inches	Inches	Inches	Inches
20	.3555	.3577	.3599	.3621	.3643	.3665
21	.37295	.37515	.37735	.37955	.38175	.38395
22	.3904	.3926	.3948	.3970	.3992	.4014
23	.40785	.41005	.41225	.41445	.41665	.41885
24	.4253	.4275	.4297	.4319	.4341	.4363
25	.44275	.44495	.44715	.44935	.45155	.45375
26	.46020	.46240	.46460	.46680	.46900	.47120
27	.47765	.47985	.48205	.48425	.48645	.48860
28	.4951	.4973	.4995	.5017	.5039	.5061
29	.51255	.51475	.51695	.51915	.52135	.52355
30	.5300	.5322	.5344	.5366	.5388	.5410
31	.54745	.54965	.55185	.55405	.55625	.55845
32	.56490	.56710	.56930	.57150	.57370	.57590
33	.5824	.5846	.5868	.5890	.5912	.5934
34	.59985	.60205	.60425	.60645	.60865	.61085
35	.61730	.61950	.62170	.62390	.62610	.62830
36	.6347	.6369	.6391	.6413	.6435	.6457
37	.65215	.65435	.65455	.65875	.66095	.66315
38	.66960	.67180	.67400	.67620	.67840	.68060
39	.6870	.6892	.6914	.6936	.6958	.6980
40	.70445	.70665	.70885	.71105	.71325	.71545
41	.72190	.72415	.72630	.72840	.73070	.73290
42	.7394	.7416	.7438	.7460	.7482	.7504
43	.75685	.75905	.76125	.76345	.76565	.76785
44	.77430	.77650	.77870	.78090	.78310	.78530
45	.7919	.7941	.7963	.7985	.8007	.8029
46	.80935	.81155	.81375	.81595	.81815	.82035
47	.82680	.82900	.83120	.83340	.83560	.83780
48	.8442	.8464	.8486	.8508	.8530	.8552
49	.86165	.86385	.86605	.86825	.87045	.87265
50	.87910	.88130	.88350	.88570	.88790	.89010
51	.8965	.8982	.9004	.9026	.9050	.9072
52	.91395	.91565	.91785	.92005	.92245	.92405
53	.93140	.93310	.93530	.93750	.93990	.94150
54	.9489	.9511	.9533	.9555	.9577	.9599
55	.96635	.96855	.97075	.97295	.97315	.97735
56	.98380	.98600	.98820	.99040	.99260	.99480
57	1.0012	1.0034	1.0056	1.0078	1.0100	1.0122
58	1.01865	1.02085	1.02305	1.02525	1.02745	1.02965
59	1.03610	1.03830	1.04050	1.04270	1.04490	1.04710
60	1.0536	1.0558	1.0580	1.0602	1.0624	1.0646
61	1.07105	1.07325	1.07545	1.07765	1.07985	1.08205
62	1.08850	1.09070	1.09290	1.09510	1.09730	1.09950
63	1.1059	1.1081	1.1103	1.1125	1.1147	1.1169
64	1.12335	1.12555	1.12775	1.12995	1.13215	1.13435
65	1.14080	1.14300	1.14520	1.14740	1.14960	1.15180
66	1.1583	1.1605	1.1627	1.1649	1.1671	1.1693
67	1.17575	1.17795	1.18015	1.18235	1.18455	1.18675
68	1.19320	1.19540	1.19760	1.19980	1.20200	1.20420
69	1.2106	1.2128	1.2150	1.2172	1.2194	1.2216
70	1.22805	1.23025	1.23245	1.23465	1.23685	1.23905
71	1.24550	1.24770	1.24990	1.25210	1.25430	1.25650
72	1.2629	1.2651	1.2673	1.2695	1.2717	1.2739

Circumferences and Areas of Circles

Diam.	Circum.	Area
16	50.265	201.06
1/8	50.658	204.22
1/4	51.051	207.39
3/8	51.444	210.60
1/2	51.836	213.82
5/8	52.229	217.08
3/4	52.622	220.35
7/8	53.014	223.65
17	53.407	226.98
1/8	53.800	230.33
1/4	54.192	233.71
3/8	54.585	237.10
1/2	54.978	240.53
5/8	55.371	243.98
3/4	55.763	247.45
7/8	56.156	250.95
18	56.549	254.47
1/8	56.941	258.02
1/4	57.334	261.59
3/8	57.727	265.18
1/2	58.119	268.80
5/8	58.512	272.45
3/4	58.905	276.12
7/8	59.298	279.81
19	59.690	283.53
1/8	60.083	287.27
1/4	60.476	291.04
3/8	60.868	294.83
1/2	61.261	298.65
5/8	61.654	302.49
3/4	62.046	306.35
7/8	62.439	310.24
20	62.832	314.16
1/8	63.225	318.10
1/4	63.617	322.06
3/8	64.010	326.05
1/2	64.403	330.06
5/8	64.795	334.10
3/4	65.188	338.16
7/8	65.581	342.25
21	65.973	346.36
1/8	66.366	350.50
1/4	66.759	354.66
3/8	67.152	358.84
1/2	67.544	363.05
5/8	67.937	367.28
3/4	68.330	371.54
7/8	68.722	375.83
22	69.115	380.13
1/8	69.508	384.46
1/4	69.900	388.82
3/8	70.293	393.20
1/2	70.686	397.61
5/8	71.079	402.04
3/4	71.471	406.49
7/8	71.864	410.97
23	72.257	415.48
23 1/8	72.649	420.00
1/4	73.042	424.56
3/8	73.435	429.13
1/2	73.827	433.74
5/8	74.220	438.36
3/4	74.613	443.01
7/8	75.006	447.69
24	75.398	452.39
1/8	75.791	457.11
1/4	76.184	461.86
3/8	76.576	466.64
1/2	76.969	471.44
5/8	77.362	476.26
3/4	77.754	481.11
7/8	78.147	485.98
25	78.540	490.87
1/8	78.933	495.79
1/4	79.325	500.74
3/8	79.718	505.71
1/2	80.111	510.71
5/8	80.503	515.72
3/4	80.896	520.77
7/8	81.289	525.84
26	81.681	530.93
1/8	82.074	536.05
1/4	82.467	541.19
3/8	82.860	546.35
1/2	83.252	551.55
5/8	83.645	556.76
3/4	84.038	562.00
7/8	84.430	567.27
27	84.823	572.56
1/8	85.216	577.87
1/4	85.608	583.21
3/8	86.001	588.57
1/2	86.394	593.96
5/8	86.786	599.37
3/4	87.179	604.81
7/8	87.572	610.27
28	87.965	615.75
1/8	88.357	621.26
1/4	88.750	626.80
3/8	89.143	632.36
1/2	89.535	637.94
5/8	89.928	643.55
3/4	90.321	649.18
7/8	90.713	654.84
29	91.106	660.52
1/8	91.499	666.23
1/4	91.892	671.96
3/8	92.284	677.71
1/2	92.677	683.49
5/8	93.070	689.30
3/4	93.462	695.13
7/8	93.855	700.98
30	94.248	706.86
1/8	94.640	712.76
30 1/4	95.033	718.69
3/8	95.426	724.64
1/2	95.819	730.62
5/8	96.211	736.62
3/4	96.604	742.64
7/8	96.997	748.69
31	97.389	754.77
1/8	97.782	760.87
1/4	98.175	766.99
3/8	98.567	773.14
1/2	98.960	779.31
5/8	99.353	785.51
3/4	99.746	791.73
7/8	100.138	797.98
32	100.531	804.25
1/8	100.924	810.54
1/4	101.316	816.86
3/8	101.709	823.21
1/2	102.102	829.58
5/8	102.494	835.97
3/4	102.887	842.39
7/8	103.280	848.83
33	103.673	855.30
1/8	104.065	861.79
1/4	104.458	868.31
3/8	104.851	874.85
1/2	105.243	881.41
5/8	105.636	888.00
3/4	106.029	894.62
7/8	106.421	901.26
34	106.814	907.92
1/8	107.207	914.61
1/4	107.600	921.32
3/8	107.992	928.06
1/2	108.385	934.82
5/8	108.778	941.61
3/4	109.170	948.42
7/8	109.563	955.25
35	109.956	962.11
1/8	110.348	969.00
1/4	110.741	975.91
3/8	111.134	982.84
1/2	111.527	989.80
5/8	111.919	996.78
3/4	112.312	1003.8
7/8	112.705	1010.8
36	113.097	1017.9
1/8	113.490	1025.0
1/4	113.883	1032.1
3/8	114.275	1039.2
1/2	114.668	1046.3
5/8	115.061	1053.5
3/4	115.454	1060.7
7/8	115.846	1068.0
37	116.239	1075.2
1/8	116.632	1082.5
1/4	117.024	1089.8

Circumferences and Areas of Circles—Continued

Diam.	Circum.	Area
37	116.239	1074.7
3/8	116.632	1080.8
1/2	117.024	1086.8
5/8	117.417	1097.1
3/4	117.810	1104.5
7/8	118.202	1111.8
38	118.596	1119.2
1/8	118.988	1126.7
1/4	119.381	1134.1
3/8	119.773	1141.6
1/2	120.166	1149.1
5/8	120.559	1156.6
3/4	120.951	1164.2
7/8	121.344	1171.7
39	121.737	1179.3
1/8	122.129	1186.9
1/4	122.522	1194.6
3/8	122.915	1202.3
1/2	123.308	1210.6
5/8	123.700	1217.7
3/4	124.093	1225.4
7/8	124.486	1233.2
40	124.878	1241.0
1/8	125.271	1248.8
1/4	125.664	1256.6
3/8	126.056	1264.5
1/2	126.449	1272.4
5/8	126.842	1280.3
3/4	127.235	1288.2
7/8	127.627	1296.2
41	128.020	1304.2
1/8	128.413	1312.2
1/4	128.805	1320.3
3/8	129.198	1328.3
1/2	129.591	1336.4
5/8	129.983	1344.5
3/4	130.376	1352.7
7/8	130.769	1360.8
42	131.161	1369.0
1/8	131.554	1377.2
1/4	131.947	1385.4
3/8	132.340	1393.7
1/2	132.732	1402.0
5/8	133.125	1410.3
3/4	133.518	1418.6
7/8	133.910	1427.0
43	134.303	1435.4
1/8	134.696	1443.8
1/4	135.088	1452.2
3/8	135.481	1460.7
1/2	135.874	1469.1
5/8	136.267	1477.6
3/4	136.659	1486.2
7/8	137.052	1494.7
44	137.445	1503.3
1/8	137.837	1511.9
1/4	138.230	1520.5
3/8	138.623	1529.2
1/2	139.015	1537.9
5/8	139.408	1546.6
3/4	139.801	1555.3
7/8	140.194	1564.0
45	140.586	1572.8
1/8	140.979	1581.6
1/4	141.372	1590.4
3/8	141.764	1599.3
1/2	142.157	1608.2
5/8	142.550	1617.0
3/4	142.942	1626.0
7/8	143.335	1634.9
46	143.728	1643.9
1/8	144.121	1652.9
1/4	144.513	1661.9
3/8	144.906	1670.9
1/2	145.299	1680.0
5/8	145.691	1689.1
3/4	146.084	1698.2
7/8	146.477	1707.4
47	146.869	1716.5
1/8	147.262	1725.7
1/4	147.655	1734.9
3/8	148.048	1744.2
1/2	148.440	1753.5
5/8	148.833	1762.7
3/4	149.226	1772.1
7/8	149.618	1781.4
48	150.011	1790.8
1/8	150.404	1800.1
1/4	150.796	1809.6
3/8	151.189	1819.0
1/2	151.582	1828.5
5/8	151.975	1837.9
3/4	152.367	1847.5
7/8	152.760	1857.0
49	153.153	1866.5
1/8	153.545	1876.1
1/4	153.938	1885.7
3/8	154.331	1895.4
1/2	154.723	1905.0
5/8	155.116	1914.7
3/4	155.509	1924.4
7/8	155.902	1934.2
50	156.294	1943.9
1/8	156.687	1953.7
1/4	157.080	1963.5
3/8	157.472	1973.3
1/2	157.865	1983.2
5/8	158.258	1993.1
3/4	158.650	2003.0
7/8	159.043	2012.9
51	159.436	2022.8
1/8	159.829	2032.8
1/4	160.221	2042.8
3/8	160.614	2052.8
1/2	161.007	2062.9
5/8	161.399	2073.0
3/4	161.792	2083.1
7/8	162.185	2093.2
52	162.577	2103.3
1/8	162.970	2113.5
1/4	163.363	2123.7
3/8	163.756	2133.9
1/2	164.148	2144.2
5/8	164.541	2154.5
3/4	164.934	2164.8
7/8	165.326	2175.1
53	165.719	2185.4
1/8	166.112	2195.8
1/4	166.504	2206.2
3/8	166.897	2216.6
1/2	167.290	2227.0
5/8	167.683	2237.5
3/4	168.075	2248.0
7/8	168.468	2258.5
54	168.861	2269.1
1/8	169.253	2279.6
1/4	169.646	2290.2
3/8	170.039	2300.8
1/2	170.431	2311.5
5/8	170.824	2322.1
3/4	171.217	2332.8
7/8	171.609	2343.5
55	172.002	2354.3
1/8	172.395	2365.0
1/4	172.788	2375.8
3/8	173.180	2386.6
1/2	173.573	2397.5
5/8	173.966	2408.3
3/4	174.358	2419.2
7/8	174.751	2430.1
56	175.144	2441.1
1/8	175.536	2452.0
1/4	175.929	2463.0
3/8	176.322	2474.0
1/2	176.715	2485.0
5/8	177.107	2496.1
3/4	177.500	2507.2
7/8	177.893	2518.3
57	178.285	2529.4
1/8	178.678	2540.6
1/4	179.071	2551.8
3/8	179.463	2563.0
1/2	179.856	2574.2
5/8	180.249	2585.4
3/4	180.642	2596.7
7/8	181.034	2608.0
58	181.427	2619.4
1/8	181.820	2630.7
1/4	182.212	2642.1
3/8	182.605	2653.5
1/2	182.998	2664.9
5/8	183.390	2676.4
3/4	183.783	2687.8
7/8	184.176	2699.3

Circumferences and Areas of Circles—Continued

Diam.	Circum.	Area	Diam.	Circum.	Area	Diam.	Circum.	Area
58	184.569	2710.9	65	206.952	3408.2	73	229.336	4185.4
⅛	184.961	2722.4				⅛	229.729	4199.7
			66	207.345	3421.2	¼	230.122	4214.1
59	185.354	2734.0	⅛	207.738	3434.2	⅜	230.514	4228.5
⅛	185.747	2745.6	¼	208.131	3447.2	½	230.907	4242.9
¼	186.139	2757.2	⅜	208.523	3460.2	⅝	231.300	4257.4
⅜	186.532	2768.8	½	208.916	3473.2	¾	231.692	4271.8
½	186.925	2780.5	⅝	209.309	3486.3	⅞	232.085	4286.3
⅝	187.317	2792.2	¾	209.701	3499.4			
¾	187.710	2803.9	⅞	210.094	3512.5	74	232.478	4300.8
⅞	188.103	2815.7				⅛	232.871	4315.4
			67	210.487	3525.7	¼	233.263	4329.9
60	188.496	2827.4	⅛	210.879	3538.8	⅜	233.656	4344.5
⅛	188.888	2839.2	¼	211.272	3552.0	½	234.049	4359.2
¼	189.281	2851.0	⅜	211.665	3565.2	⅝	234.441	4373.8
⅜	189.674	2862.9	½	212.058	3578.5	¾	234.834	4388.5
½	190.066	2874.8	⅝	212.450	3591.7	⅞	235.227	4403.1
⅝	190.459	2886.6	¾	212.843	3605.0			
¾	190.852	2898.6	⅞	213.236	3618.3	75	235.619	4417.9
⅞	191.244	2910.5				⅛	236.012	4432.6
			68	213.628	3631.7	¼	236.405	4447.4
61	191.637	2922.5	⅛	214.021	3645.0	⅜	236.798	4462.2
⅛	192.030	2934.5	¼	214.414	3658.4	½	237.190	4477.0
¼	192.423	2946.5	⅜	214.806	3671.8	⅝	237.583	4491.8
⅜	192.815	2958.5	½	215.199	3685.3	¾	237.976	4506.7
½	193.208	2970.6	⅝	215.592	3698.7	⅞	238.368	4521.5
⅝	193.601	2982.7	¾	215.984	3712.2			
¾	193.993	2994.8	⅞	216.377	3725.7	76	238.761	4536.5
⅞	194.386	3006.9				⅛	239.154	4551.4
			69	216.770	3739.3	¼	239.546	4566.4
62	194.779	3019.1	⅛	217.163	3752.8	⅜	239.939	4581.3
⅛	195.171	3031.3	¼	217.555	3766.4	½	240.332	4596.3
¼	195.564	3043.5	⅜	217.948	3780.0	⅝	240.725	4611.4
⅜	195.957	3055.7	½	218.341	3793.7	¾	241.117	4626.4
½	196.350	3068.0	⅝	218.733	3807.3	⅞	241.510	4641.5
⅝	196.742	3080.3	¾	219.126	3821.0			
¾	197.135	3092.6	⅞	219.519	3834.7	77	241.903	4656.6
⅞	197.528	3104.9				⅛	242.295	4671.8
			70	219.911	3848.5	¼	242.688	4686.9
63	197.920	3117.2	⅛	220.304	3862.2	⅜	243.081	4702.1
⅛	198.313	3129.6	¼	220.697	3876.0	½	243.473	4717.3
¼	198.706	3142.0	⅜	221.090	3889.8	⅝	243.866	4732.5
⅜	199.098	3154.5	½	221.482	3903.6	¾	244.259	4747.8
½	199.491	3166.9	⅝	221.875	3917.5	⅞	244.652	4763.1
⅝	199.884	3179.4	¾	222.268	3931.4			
¾	200.277	3191.9	⅞	222.660	3945.3	78	245.044	4778.4
⅞	200.669	3204.4				⅛	245.437	4793.7
			71	223.053	3959.2	¼	245.830	4809.0
64	201.062	3217.0	⅛	223.446	3973.1	⅜	246.222	4824.4
⅛	201.455	3229.6	¼	223.838	3987.1	½	246.615	4839.8
¼	201.847	3242.2	⅜	224.231	4001.1	⅝	247.008	4855.2
⅜	202.240	3254.8	½	224.624	4015.2	¾	247.400	4870.7
½	202.633	3267.5	⅝	225.017	4029.2	⅞	247.793	4886.2
⅝	203.025	3280.1	¾	225.409	4043.3			
¾	203.418	3292.8	⅞	225.802	4057.4	79	248.186	4901.7
⅞	203.811	3305.6				⅛	248.579	4917.2
			72	226.195	4071.5	¼	248.971	4932.7
65	204.204	3318.3	⅛	226.587	4085.7	⅜	249.364	4948.3
⅛	204.596	3331.1	¼	226.980	4099.8	½	249.757	4963.9
¼	204.989	3343.9	⅜	227.373	4114.0	⅝	250.149	4979.5
⅜	205.382	3356.7	½	227.765	4128.2	¾	250.542	4995.2
½	205.774	3369.6	⅝	228.158	4142.5	⅞	250.935	5010.9
⅝	206.167	3382.4	¾	228.551	4156.8			
¾	206.560	3395.3	⅞	228.944	4171.1	80	251.327	5026.5

Circumferences and Areas of Circles—Concluded

Diam.	Circum.	Area
80	251.720	5042.3
1/8	252.113	5058.0
1/4	252.506	5073.8
3/8	252.898	5089.6
1/2	253.291	5105.4
5/8	253.684	5121.2
3/4	254.076	5137.1
7/8		
81	254.469	5153.0
1/8	254.862	5168.9
1/4	255.254	5184.9
3/8	255.647	5200.8
1/2	256.040	5216.8
5/8	256.433	5232.8
3/4	256.825	5248.9
7/8	257.218	5264.9
82	257.611	5281.0
1/8	258.003	5297.1
1/4	258.396	5313.3
3/8	258.789	5329.4
1/2	259.181	5345.6
5/8	259.574	5361.8
3/4	259.967	5378.1
7/8	260.359	5394.3
83	260.752	5410.6
1/8	261.145	5426.9
1/4	261.538	5443.3
3/8	261.930	5459.6
1/2	262.323	5476.0
5/8	262.716	5492.4
3/4	263.108	5508.8
7/8	263.501	5525.3
84	263.894	5541.8
1/8	264.286	5558.3
1/4	264.679	5574.8
3/8	265.072	5591.4
1/2	265.465	5607.9
5/8	265.857	5624.5
3/4	266.250	5641.2
7/8	266.643	5657.8
85	267.035	5674.5
1/8	267.428	5691.2
1/4	267.821	5707.9
3/8	268.213	5724.7
1/2	268.606	5741.5
5/8	268.999	5758.3
3/4	269.392	5775.1
7/8	269.784	5791.9
86	270.177	5808.8
1/8	270.570	5825.7
1/4	270.962	5842.6
3/8	271.355	5859.6
1/2	271.748	5876.5
5/8	272.140	5893.5
3/4	272.533	5910.6
7/8	272.926	5927.6
87	273.319	5944.7
1/8	273.711	5961.8
87 1/4	274.104	5978.9
3/8	274.497	5996.0
1/2	274.889	6013.2
5/8	275.282	6030.4
3/4	275.675	6047.6
7/8	276.067	6064.9
88	276.460	6082.1
1/8	276.853	6099.4
1/4	277.246	6116.7
3/8	277.638	6134.1
1/2	278.031	6151.4
5/8	278.424	6168.8
3/4	278.816	6186.2
7/8	279.209	6203.7
89	279.602	6221.1
1/8	279.994	6238.6
1/4	280.387	6256.1
3/8	280.780	6273.7
1/2	281.173	6291.2
5/8	281.565	6308.8
3/4	281.958	6326.4
7/8	282.351	6344.1
90	282.743	6361.7
1/8	283.136	6379.4
1/4	283.529	6397.1
3/8	283.921	6414.9
1/2	284.314	6432.6
5/8	284.707	6450.4
3/4	285.100	6468.2
7/8	285.492	6486.0
91	285.885	6503.9
1/8	286.278	6521.8
1/4	286.670	6539.7
3/8	287.063	6567.6
1/2	287.456	6575.5
5/8	287.848	6593.5
3/4	288.241	6611.5
7/8	288.634	6629.6
92	289.027	6647.6
1/8	289.419	6665.7
1/4	289.812	6683.8
3/8	290.205	6701.9
1/2	290.597	6720.1
5/8	290.990	6738.2
3/4	291.383	6756.4
7/8	291.775	6774.7
93	292.168	6792.9
1/8	292.561	6811.2
1/4	292.954	6829.5
3/8	293.346	6847.8
1/2	293.739	6866.1
5/8	294.132	6884.5
3/4	294.524	6902.9
7/8	294.917	6921.3
94	295.310	6939.8
1/8	295.702	6958.2
1/4	296.095	6976.7
94 3/8	296.488	6995.3
1/2	296.881	7013.4
5/8	297.273	7032.5
3/4	297.666	7051.0
7/8	298.059	7069.6
95	298.451	7088.2
1/8	298.844	7106.9
1/4	299.237	7125.6
3/8	299.629	7144.3
1/2	300.022	7163.0
5/8	300.415	7181.8
3/4	300.807	7200.6
7/8	301.200	7219.4
96	301.593	7238.2
1/8	301.986	7257.1
1/4	302.378	7276.0
3/8	302.771	7294.9
1/2	303.164	7313.8
5/8	303.556	7332.8
3/4	303.949	7351.8
7/8	304.342	7370.8
97	304.734	7389.8
1/8	305.127	7408.9
1/4	305.520	7428.0
3/8	305.913	7447.1
1/2	306.305	7466.2
5/8	306.698	7485.3
3/4	307.091	7504.5
7/8	307.483	7523.7
98	307.876	7543.0
1/8	308.269	7562.2
1/4	308.661	7581.5
3/8	309.054	7600.8
1/2	309.447	7620.1
5/8	309.840	7639.5
3/4	310.232	7658.9
7/8	310.625	7678.3
99	311.018	7697.7
1/8	311.410	7717.1
1/4	311.803	7736.6
3/8	312.196	7756.1
1/2	312.588	7775.6
5/8	312.981	7795.2
3/4	313.374	7814.8
7/8	313.767	7834.4
100	314.159	7854.0

Lengths of the Arcs of Circles to the Radius 1

	Degrees		Minutes		Seconds	
0	0.00000 00000	60	1.04719 75512	120	2.09439 51024	0	0.00000 00000	0	0.00000 00000
1	0.01745 32925	61	1.06465 08437	121	2.11184 83949	1	0.00029 08882	1	0.00000 48481
2	0.03490 65850	62	1.08210 41362	122	2.12930 16874	2	0.00058 17764	2	0.00000 96963
3	0.05235 98776	63	1.09955 74288	123	2.14675 49800	3	0.00087 26646	3	0.00001 45444
4	0.06981 31701	64	1.11701 07213	124	2.16420 82725	4	0.00116 35528	4	0.00001 93925
5	0.08726 64626	65	1.13446 40138	125	2.18166 15650	5	0.00145 44410	5	0.00002 42407
6	0.10471 97551	66	1.15191 73063	126	2.19911 48575	6	0.00174 53293	6	0.00002 90888
7	0.12217 30476	67	1.16937 05988	127	2.21656 81500	7	0.00203 62175	7	0.00003 39370
8	0.13962 63402	68	1.18682 38914	128	2.23402 14426	8	0.00232 71057	8	0.00003 87851
9	0.15707 96327	69	1.20427 71839	129	2.25147 47351	9	0.00261 79939	9	0.00004 36332
10	0.17453 29252	70	1.22173 04764	130	2.26892 80276	10	0.00290 88821	10	0.00004 84814
11	0.19198 62177	71	1.23918 37689	131	2.28638 13201	11	0.00319 97703	11	0.00005 33295
12	0.20943 95102	72	1.25663 70614	132	2.30383 46126	12	0.00349 06585	12	0.00005 81776
13	0.22689 28028	73	1.27409 03540	133	2.32128 79052	13	0.00378 15467	13	0.00006 30258
14	0.24434 60953	74	1.29154 36465	134	2.33874 11977	14	0.00407 24349	14	0.00006 78739
15	0.26179 93878	75	1.30899 69390	135	2.35619 44902	15	0.00436 33231	15	0.00007 27221
16	0.27925 26803	76	1.32645 02315	136	2.37364 77827	16	0.00465 42113	16	0.00007 75702
17	0.29670 59728	77	1.34390 35240	137	2.39110 10752	17	0.00494 50995	17	0.00008 24183
18	0.31415 92654	78	1.36135 68166	138	2.40855 43678	18	0.00523 59878	18	0.00008 72665
19	0.33161 25579	79	1.37881 01091	139	2.42600 76603	19	0.00552 68760	19	0.00009 21146
20	0.34906 58504	80	1.39626 34016	140	2.44346 09528	20	0.00581 77642	20	0.00009 69627
21	0.36651 91429	81	1.41371 66941	141	2.46091 42453	21	0.00610 86524	21	0.00010 18109
22	0.38397 24354	82	1.43116 99866	142	2.47836 75378	22	0.00639 95406	22	0.00010 66590
23	0.40142 57280	83	1.44862 32792	143	2.49582 08304	23	0.00669 04288	23	0.00011 15071
24	0.41887 90205	84	1.46607 65717	144	2.51328 41229	24	0.00698 13170	24	0.00011 63553
25	0.43633 23130	85	1.48352 98642	145	2.53072 74154	25	0.00727 22052	25	0.00012 12034
26	0.45378 56055	86	1.50098 31567	146	2.54818 07079	26	0.00756 30934	26	0.00012 60516
27	0.47123 88980	87	1.51843 64492	147	2.56563 40004	27	0.00785 39816	27	0.00013 08997
28	0.48869 21906	88	1.53588 97418	148	2.58308 72930	28	0.00814 48698	28	0.00013 57478
29	0.50614 54831	89	1.55334 30343	149	2.60054 05855	29	0.00843 57581	29	0.00014 05960
30	0.52359 87756	90	1.57079 63268	150	2.61799 38780	30	0.00872 66463	30	0.00014 54441
31	0.54105 20681	91	1.58824 96193	151	2.63544 71705	31	0.00901 75345	31	0.00015 02922
32	0.55850 53606	92	1.60570 29118	152	2.65290 04630	32	0.00930 84227	32	0.00015 51404
33	0.57595 86532	93	1.62315 62044	153	2.67035 37556	33	0.00959 93109	33	0.00015 99885
34	0.59341 19457	94	1.64060 94969	154	2.68780 70481	34	0.00989 01991	34	0.00016 48367
35	0.61086 52382	95	1.65806 27894	155	2.70526 03406	35	0.01018 10873	35	0.00016 96848
36	0.62831 85307	96	1.67551 60819	156	2.72271 36331	36	0.01047 19755	36	0.00017 45329
37	0.64577 18232	97	1.69296 93744	157	2.74016 69256	37	0.01076 28637	37	0.00017 93811
38	0.66322 51158	98	1.71042 26670	158	2.75762 02182	38	0.01105 37519	38	0.00018 42292
39	0.68067 84083	99	1.72787 59595	159	2.77507 35107	39	0.01134 46401	39	0.00018 90773
40	0.69813 17008	100	1.74532 92520	160	2.79252 68032	40	0.01163 55283	40	0.00019 39255
41	0.71558 49933	101	1.76278 25445	161	2.80998 00957	41	0.01192 64166	41	0.00019 87736
42	0.73303 82858	102	1.78023 58370	162	2.82743 33882	42	0.01221 73048	42	0.00020 36217
43	0.75049 15784	103	1.79768 91296	163	2.84488 66808	43	0.01250 81930	43	0.00020 84699
44	0.76794 48709	104	1.81514 24221	164	2.86233 99733	44	0.01279 90812	44	0.00021 33180
45	0.78539 81634	105	1.83259 57146	165	2.87979 32658	45	0.01308 99694	45	0.00021 81662
46	0.80285 14559	106	1.85004 90071	166	2.89724 65583	46	0.01338 08576	46	0.00022 30143
47	0.82030 47484	107	1.86750 22996	167	2.91469 98508	47	0.01367 17458	47	0.00022 78624
48	0.83775 80410	108	1.88495 55922	168	2.93215 31434	48	0.01396 26340	48	0.00023 27106
49	0.85521 13335	109	1.90240 88847	169	2.94960 64359	49	0.01425 35222	49	0.00023 75587
50	0.87266 46260	110	1.91986 21772	170	2.96705 97284	50	0.01454 44104	50	0.00024 24068
51	0.89011 79185	111	1.93731 54697	171	2.98451 30209	51	0.01483 52986	51	0.00024 72550
52	0.90757 12110	112	1.95476 87622	172	3.00196 63134	52	0.01512 61869	52	0.00025 21031
53	0.92502 45036	113	1.97222 20548	173	3.01941 96060	53	0.01541 70751	53	0.00025 69513
54	0.94247 77961	114	1.98967 53473	174	3.03687 28985	54	0.01570 79633	54	0.00026 17994
55	0.95993 10886	115	2.00712 86398	175	3.05432 61910	55	0.01599 88515	55	0.00026 66475
56	0.97738 43811	116	2.02458 19323	176	3.07177 94835	56	0.01628 97397	56	0.00027 14958
57	0.99483 76736	117	2.04203 52248	177	3.08923 27760	57	0.01658 06279	57	0.00027 63437
58	1.01229 09662	118	2.05948 85174	178	3.10668 60685	58	0.01687 15161	58	0.00028 11919
59	1.02974 42587	119	2.07694 18099	179	3.12413 93611	59	0.01716 24043	59	0.00028 60401
60	1.04719 75512	120	2.09439 51024	180	3.14159 26536	60	0.01745 32925	60	0.00029 08882

Length Correction for 100.00 Feet

FROM 0 TO 5.9 RISE

Rise	Angle	Cor.	Rise	Angle	Cor.	Rise	Angle	Cor.
.0	....	.....	2.0	1°-09′	.02014	4.0	2°-18′	.08056
.1	....	.....	2.1	1°-13′	.02255	4.1	2°-21′	.08410
.2	....	.....	2.2	1°-16′	.02444	4.2	2°-25′	.08894
.3	0°-11′	.00051	2.3	1°-20′	.02708	4.3	2°-28′	.09266
.4	0°-14′	.00083	2.4	1°-23′	.02914	4.4	2°-32′	.09773
.5	0°-18′	.00137	2.5	1°-26′	.03129	4.5	2°-35′	.10163
.6	0°-21′	.00187	2.6	1°-30′	.03427	4.6	2°-39′	.10694
.7	0°-25′	.00264	2.7	1°-33′	.03659	4.7	2°-42′	.11101
.8	0°-28′	.00332	2.8	1°-37′	.03980	4.8	2°-46′	.11656
.9	0°-31′	.00407	2.9	1°-40′	.04231	4.9	2°-49′	.12081
1.0	0°-35′	.00518	3.0	1°-44′	.04576	5.0	2°-52′	.12514
1.1	0°-38′	.00611	3.1	1°-47′	.04843	5.1	2°-56′	.13102
1.2	0°-42′	.00746	3.2	1°-50′	.05119	5.2	2°-59′	.13553
1.3	0°-45′	.00857	3.3	1°-54′	.05498	5.3	3°-03′	.14165
1.4	0°-49′	.01016	3.4	1°-57′	.05791	5.4	3°-06′	.14633
1.5	0°-52′	.01144	3.5	2°-01′	.06194	5.5	3°-09′	.15109
1.6	0°-55′	.01280	3.6	2°-04′	.06505	5.6	3°-12′	.15592
1.7	0°-59′	.01473	3.7	2°-08′	.06931	5.7	3°-16′	.16249
1.8	1°-02′	.01626	3.8	2°-11′	.07260	5.8	3°-20′	.16918
1.9	1°-06′	.01843	3.9	2°-15′	.07716	5.9	3°-23′	.17430

FROM 6.0 TO 11.9 RISE

Rise	Angle	Cor.	Rise	Angle	Cor.	Rise	Angle	Cor.
6.0	3°-27′	.18123	8.0	4°-35′	.32085	10.0	5°-43′	.49982
6.1	3°-30′	.18652	8.1	4°-38′	.32786	10.1	5°-47′	.51159
6.2	3°-33′	.19189	8.2	4°-42′	.33739	10.2	5°-50′	.52052
6.3	3°-36′	.19733	8.3	4°-45′	.34463	10.3	5°-53′	.52952
6.4	3°-40′	.20470	8.4	4°-49′	.35442	10.4	5°-57′	.54165
6.5	3°-44′	.21221	8.5	4°-52′	.36182	10.5	6°-00′	.55083
6.6	3°-47′	.21793	8.6	4°-55′	.36932	10.6	6°-04′	.56319
6.7	3°-50′	.22373	8.7	4°-59′	.37943	10.7	6°-07′	.57256
6.8	3°-54′	.23157	8.8	5°-02′	.38711	10.8	6°-10′	.58201
6.9	3°-57′	.23812	8.9	5°-06′	.39746	10.9	6°-14′	.59472
7.0	4°-01′	.24563	9.0	5°-09′	.40532	11.0	6°-17′	.60435
7.1	4°-04′	.25178	9.1	5°-12′	.41325	11.1	6°-21′	.61731
7.2	4°-07′	.25801	9.2	5°-16′	.42396	11.2	6°-24′	.62712
7.3	4°-11′	.26643	9.3	5°-19′	.43207	11.3	6°-27′	.63700
7.4	4°-14′	.27283	9.4	5°-23′	.44303	11.4	6°-31′	.65031
7.5	4°-18′	.28149	9.5	5°-26′	.45133	11.5	6°-34′	.66038
7.6	4°-21′	.28807	9.6	5°-29′	.45970	11.6	6°-38′	.67394
7.7	4°-25′	.29696	9.7	5°-33′	.47098	11.7	6°-41′	.68419
7.8	4°-28′	.30372	9.8	5°-36′	.47955	11.8	6°-44′	.69453
7.9	4°-32′	.31383	9.9	5°-40′	.49107	11.9	6°-48′	.70843

Flow Equivalents

1 second-foot equals 40 California miner's inches. (Law of March 23, 1901.)

1 second-foot equals 38.4 Colorado miner's inches.

1 second-foot equals 7.48 United States gallons per second; equals 448.8 gallons per minute; equals 646,317 gallons per day.

1 second-foot equals 6.23 British imperial gallons per second.

1 second-foot for one year covers one square mile 1.131 feet deep; 13.57 inches deep.

1 second-foot for one year equals 31,536,000 cubic feet.

1 second-foot equals about one acre-inch per hour.

1 second-foot falling 10 feet equals 1.136 horse-power.

100 California miner's inches equal 18.7 United States gallons per second.

100 California miner's inches equal 96.0 Colorado miner's inches.

100 California miner's inches for one day equal 4.96 acre-feet.

100 Colorado miner's inches equal 2.60 second-feet.

100 Colorado miner's inches equal 19.5 United States gallons per second.

100 Colorado miner's inches equal 104 California miner's inches.

100 Colorado miner's inches for one day equal 5.17 acre-feet.

100 United States gallons per minute equal 0.223 second-foot.

100 United States gallons per minute for one day equal 0.442 acre-foot.

1,000,000 United States gallons per day equal 1.55 second-feet.

1,000,000 United States gallons equal 3.07 acre-feet.

1,000,000 cubic feet equal 22.96 acre-feet.

1 acre-foot equals 325,851 gallons.

1 inch deep on 1 square mile equals 2,323,200 cubic feet.

1 inch deep on 1 square mile equals .0737 second-foot per year.

Gallons and Cubic Feet

United States Gallons in a Given Number of Cubic Feet

(1 cubic foot = 7.480519 U. S. gallons; 1 gallon = 231 cubic inches = 0.13368056 cubic foot.)

Cubic feet	Gallons	Cubic feet	Gallons	Cubic feet	Gallons
0.1	0.75	50	374.0	8 000	59 844.2
0.2	1.50	60	448.8	9 000	67 324.7
0.3	2.24	70	523.6	10 000	74 805.2
0.4	2.99	80	598.4	20 000	149 610.4
0.5	3.74	90	673.2	30 000	224 415.6
0.6	4.49	100	748.1	40 000	299 220.8
0.7	5.24	200	1 496.1	50 000	374 025.9
0.8	5.98	300	2 244.2	60 000	448 831.1
0.9	6.73	400	2 992.2	70 000	523 636.3
1	7.48	500	3 740.3	80 000	598 441.5
2	14.96	600	4 488.3	90 000	673 246.7
3	22.44	700	5 236.4	100 000	748 051.9
4	29.92	800	5 984.4	200 000	1 496 103.8
5	37.40	900	6 732.5	300 000	2 244 155.7
6	44.88	1000	7 480.5	400 000	2 992 207.6
7	52.36	2000	14 961.0	500 000	3 740 259.5
8	59.84	3000	22 441.6	600 000	4 488 311.4
9	67.32	4000	29 922.1	700 000	5 236 363.3
10	74.81	5000	37 402.6	800 000	5 984 415.2
20	149.6	6000	44 883.1	900 000	6 732 467.1
30	224.4	7000	52 363.6	1 000 000	7 480 519.0
40	299.2				

Cubic Feet in a Given Number of Gallons

Cubic feet	Gallons	Cubic feet	Gallons	Cubic feet	Gallons
1	.134	1 000	133.681	1 000 000	133 680.6
2	.267	2 000	267.361	2 000 000	267 361.1
3	.401	3 000	401.042	3 000 000	401 041.7
4	.535	4 000	534.722	4 000 000	534 722.2
5	.668	5 000	668.403	5 000 000	668 402.8
6	.802	6 000	802.083	6 000 000	802 083.4
7	.936	7 000	935.764	7 000 000	935 763.9
8	1.069	8 000	1 069.444	8 000 000	1 069 444.5
9	1.203	9 000	1 203.125	9 000 000	1 203 125.0
10	3.337	10 000	1 336.806	10 000 000	1 336 805.6

Cubic Feet per Second, Gallons in 24 Hours, etc.

Cubic feet per second	1/60	1	1.5472	2.2280
Cubic feet per minute	1	60	92.834	133.681
U. S. gallons per minute	7.480519	448.83	694.444	1 000
U. S. gallons per 24 hours	10 771.95	646 317	1 000 000	1 440 000
Pounds of water (at 62° F.) per minute	62.355	3741.3	5788.65	8335.65

Contents in Cubic Feet and United States Gallons of Pipes and Cylinders of Various Inside Diameters and One Foot in Length

(1 gallon = 231 cubic inches. 1 cubic foot = 7.4805 gallons.)

Diameter in inches	For 1 ft. in length		Diameter in inches	For 1 ft. in length		Diameter in inches	For 1 ft. in length	
	Cubic feet, also area in square feet	U. S. gallons		Cubic feet, also area in square feet	U. S. gallons		Cubic feet, also area in square feet	U. S. gallons
¼	.0003	.0025	6¾	.2485	1.859	19	1.969	14.73
5/16	.0005	.0040	7	.2673	1.999	19½	2.074	15.51
⅜	.0008	.0057	7¼	.2867	2.145	20	2.182	16.32
7/16	.0010	.0078	7½	.3068	2.295	20½	2.292	17.15
½	.0014	.0102	7¾	.3276	2.450	21	2.405	17.99
9/16	.0017	.0129	8	.3491	2.611	21½	2.521	18.86
⅝	.0021	.0159	8¼	.3712	2.777	22	2.640	19.75
11/16	.0026	.0193	8½	.3941	2.948	22½	2.761	20.66
¾	.0031	.0230	8¾	.4176	3.125	23	2.885	21.58
13/16	.0036	.0269	9	.4418	3.305	23½	3.012	22.53
⅞	.0042	.0312	9¼	.4667	3.491	24	3.142	23.50
15/16	.0048	.0359	9½	.4922	3.682	25	3.409	25.50
1	.0055	.0408	9¾	.5185	3.879	26	3.687	27.58
1¼	.0085	.0638	10	.5454	4.080	27	3.976	29.74
1½	.0123	.0918	10¼	.5730	4.286	28	4.276	31.99
1¾	.0167	.1249	10½	.6013	4.498	29	4.587	34.31
2	.0218	.1632	10¾	.6303	4.715	30	4.909	36.72
2¼	.0276	.2066	11	.6600	4.937	31	5.241	39.21
2½	.0341	.2550	11¼	.6903	5.164	32	5.585	41.78
2¾	.0412	.3085	11½	.7213	5.396	33	5.940	44.43
3	.0491	.3672	11¾	.7530	5.633	34	6.305	47.16
3¼	.0576	.4309	12	.7854	5.875	35	6.681	49.98
3½	.0668	.4998	12½	.8522	6.375	36	7.069	52.88
3¾	.0767	.5738	13	.9218	6.895	37	7.467	55.86
4	.0873	.6528	13½	1.9940	7.436	38	7.876	58.92
4¼	.0985	.7369	14	1.069	7.997	39	8.296	62.06
4½	.1104	.8263	14½	1.147	8.578	40	8.727	65.28
4¾	.1231	.9206	15	1.227	9.180	41	9.168	68.58
5	.1364	1.020	15½	1.310	9.801	42	9.621	71.97
5¼	.1503	1.125	16	1.396	10.44	43	10.085	75.44
5½	.1650	1.234	16½	1.485	11.11	44	10.559	78.99
5¾	.1803	1.349	17	1.576	11.79	45	11.045	82.62
6	.1963	1.469	17½	1.670	12.49	46	11.541	86.33
6¼	.2131	1.594	18	1.767	13.22	47	12.048	90.13
6½	.2304	1.724	18½	1.867	13.96	48	12.566	94.00

To find the capacity of pipes greater than the largest given in the table, look in the table for a pipe of one-half the given size, and multiply its capacity by 4; or one of one-third its size, and multiply its capacity by 9, etc.

To find the weight of water in any of the given sizes, multiply the capacity in cubic feet by 62½ or the capacity in gallons by 8⅓, or, if a more accurate result is required, by the weight of a cubic foot of water at the actual temperature in the pipe.

Given the dimensions of a cylinder in inches, to find its capacity in U. S. gallons: Square the diameter, multiply by the length and by 0.0034. If d = diameter, l = length, gallons $= \frac{d^2 \times 0.7854 \times l}{231} = 0.0034\ d^2 l$. If D and L are in feet, gallons $= 5.875 D^2 L$.

Number of Barrels (31½ Gallons) in Cylindrical Cisterns and Tanks

(1 barrel = 31½ gallons = 31.5 × 231/1728 = 4.21094 cu. ft.; reciprocal = 0.237477.)

Depth in feet	Diameter in feet								
	5	6	7	8	9	10	11	12	13
1	4.663	6.714	9.139	11.937	15.108	18.652	22.569	26.859	31.522
5	23.3	33.6	45.7	59.7	75.5	93.3	112.8	134.3	157.6
6	28.0	40.3	54.8	71.6	90.6	111.9	135.4	161.2	189.1
7	32.6	47.0	64.0	83.6	105.8	130.6	158.0	188.0	220.7
8	37.3	53.7	73.1	95.5	120.9	149.2	180.6	214.9	252.2
9	42.0	60.4	82.3	107.4	136.0	167.9	203.1	241.7	283.7
10	46.6	67.1	91.4	119.4	151.1	186.5	225.7	268.6	315.2
11	51.3	73.9	100.5	131.3	166.2	205.2	248.3	295.4	346.7
12	56.0	80.6	109.7	143.2	181.3	223.8	270.8	322.3	378.3
13	60.6	87.3	118.8	155.2	196.4	242.5	293.4	349.2	409.8
14	65.3	94.0	127.9	167.1	211.5	261.1	316.0	376.0	441.3
15	69.9	100.7	137.1	179.1	226.6	279.8	338.5	402.9	472.8
16	74.6	107.4	146.2	191.0	241.7	298.4	361.1	429.7	504.4
17	79.3	114.1	155.4	202.9	256.8	317.1	383.7	456.6	535.9
18	83.9	120.9	164.5	214.9	271.9	335.7	406.2	483.5	567.4
19	88.6	127.6	173.6	226.8	287.1	354.4	428.8	510.3	598.9
20	93.3	134.3	182.8	238.7	302.2	373.0	451.4	537.2	630.4

Depth in feet	Diameter in feet								
	14	15	16	17	18	19	20	21	22
1	36.557	41.966	47.748	53.903	60.431	67.332	74.606	82.253	90.273
5	182.8	209.8	238.7	269.5	302.2	336.7	373.0	411.3	451.4
6	219.3	251.8	286.5	323.4	362.6	404.0	447.6	493.5	541.6
7	255.9	293.8	334.2	377.3	423.0	471.3	522.2	575.8	631.9
8	292.5	335.7	382.0	431.2	483.4	538.7	596.8	658.0	722.2
9	329.0	377.7	429.7	485.1	543.9	606.0	671.5	740.3	812.5
10	365.6	419.7	477.5	539.0	604.3	673.3	746.1	822.5	902.7
11	402.1	461.6	525.2	592.9	664.7	740.7	820.7	904.8	993.0
12	438.7	503.6	573.0	646.8	725.2	808.0	895.3	987.0	1083.3
13	475.2	545.6	620.7	700.7	785.6	875.3	969.9	1069.3	1173.5
14	511.8	587.5	668.5	754.6	846.0	942.6	1044.5	1151.5	1263.8
15	548.4	629.5	716.2	808.5	906.5	1010.0	1119.1	1233.8	1354.1
16	584.9	671.5	764.0	862.4	966.9	1077.3	1193.7	1316.0	1444.4
17	621.5	713.4	811.7	916.4	1027.3	1144.6	1268.3	1398.3	1534.5
18	658.0	755.4	859.5	970.3	1087.8	1212.0	1342.9	1480.6	1624.9
19	694.6	797.4	907.2	1024.2	1148.2	1279.3	1417.5	1562.8	1715.2
20	731.1	839.3	955.0	1078.1	1208.6	1346.6	1492.1	1645.1	1805.5

Depth in feet	Diameter in feet							
	23	24	25	26	27	28	29	30
1	98.666	107.432	116.571	126.083	135.968	146.226	156.858	167.863
5	493.3	537.2	582.9	630.4	679.8	731.1	784.3	839.3
6	592.0	644.6	699.4	756.5	815.8	877.4	941.1	1007.2
7	690.7	752.0	816.0	882.6	951.8	1023.6	1098.0	1175.0
8	789.3	859.5	932.6	1008.7	1087.7	1169.8	1254.9	1342.9
9	888.0	966.9	1049.1	1134.7	1223.7	1316.0	1411.7	1510.8
10	986.7	1074.3	1165.7	1260.8	1359.7	1462.2	1568.6	1678.6
11	1085.3	1181.8	1282.3	1386.9	1495.6	1608.5	1725.4	1846.5
12	1184.0	1289.2	1398.8	1513.0	1631.6	1754.7	1882.3	2014.4
13	1282.7	1396.6	1515.4	1639.1	1767.6	1900.9	2039.2	2182.2
14	1381.3	1504.0	1632.0	1765.2	1903.6	2047.2	2196.0	2350.1
15	1480.0	1611.5	1748.6	1891.2	2039.5	2193.4	2352.9	2517.9
16	1578.7	1718.9	1865.1	2017.3	2175.5	2339.6	2509.7	2685.8
17	1677.3	1826.3	1981.7	2143.4	2311.5	2485.8	2666.6	2853.7
18	1776.0	1933.8	2098.3	2269.5	2447.4	2632.0	2823.4	3021.5
19	1874.7	2041.2	2214.8	2395.6	2583.4	2778.3	2980.3	3189.4
20	1973.3	2148.6	2321.4	2521.7	2719.4	2924.5	3137.2	3357.3

Cylindrical Vessels, Tanks and Cisterns

Diameter in Ft. and Ins., Area in Sq. Ft. and Capacity in U. S. Gals. for 1 Ft. in Depth
(1 gallon = 231 cubic inches = 1 cubic foot/7.4805 = 0.13368 cubic foot.)

Diameter, ft.	Diameter, in.	Area, square feet	Gallons, 1 foot depth.	Diameter, ft.	Diameter, in.	Area, square feet	Gallons, 1 foot depth	Diameter, ft.	Diameter, in.	Area, square feet	Gallons, 1 foot depth
1	0	.785	5.87	5	8	25.22	188.66	19	0	283.53	2120.9
1	1	.922	6.89	5	9	25.97	194.25	19	3	291.04	2177.1
1	2	1.069	8.00	5	10	26.73	199.92	19	6	298.65	2234.0
1	3	1.227	9.18	5	11	27.49	205.67	19	9	306.35	2291.7
1	4	1.396	10.44	6	0	28.27	211.51	20	0	314.16	2350.1
1	5	1.576	11.79	6	3	30.68	229.50	20	3	322.06	2409.2
1	6	1.767	13.22	6	6	33.18	248.23	20	6	330.06	2469.1
1	7	1.969	14.73	6	9	35.78	267.69	20	9	338.16	2529.6
1	8	2.182	16.32	7	0	38.48	287.88	21	0	346.36	2591.0
1	9	2.405	17.99	7	3	41.28	308.81	21	3	354.66	2653.0
1	10	2.640	19.75	7	6	44.18	330.48	21	6	363.05	2715.8
1	11	2.885	21.58	7	9	47.17	352.88	21	9	371.54	2779.3
2	0	3.142	23.50	8	0	50.27	376.01	22	0	380.13	2843.6
2	1	3.409	25.50	8	3	53.46	399.88	22	3	388.82	2908.6
2	2	3.687	27.58	8	6	56.75	424.48	22	6	397.61	2974.3
2	3	3.976	29.74	8	9	60.13	449.82	22	9	406.49	3040.8
2	4	4.276	31.99	9	0	63.62	475.89	23	0	415.48	3108.0
2	5	4.587	34.31	9	3	67.20	502.70	23	3	424.56	3175.9
2	6	4.909	36.72	9	6	70.88	530.24	23	6	433.74	3244.6
2	7	5.241	39.21	9	9	74.66	558.51	23	9	443.01	3314.0
2	8	5.585	41.78	10	0	78.54	587.52	24	0	452.39	3384.1
2	9	5.940	44.43	10	3	82.52	617.26	24	3	461.86	3455.0
2	10	6.305	47.16	10	6	86.59	647.74	24	6	471.44	3526.6
2	11	6.681	49.98	10	9	90.76	678.95	24	9	481.11	3598.9
3	0	7.069	52.88	11	0	95.03	710.90	25	0	490.87	3672.0
3	1	7.467	55.86	11	3	99.40	743.58	25	3	500.74	3745.8
3	2	7.876	58.92	11	6	103.87	776.99	25	6	510.71	3820.3
3	3	8.296	62.06	11	9	108.43	811.14	25	9	520.77	3895.6
3	4	8.727	65.28	12	0	113.10	846.03	26	0	530.93	3971.6
3	5	9.168	68.58	12	3	117.86	881.65	26	3	541.19	4048.4
3	6	9.621	71.97	12	6	122.72	918.00	26	6	551.55	4125.9
3	7	10.085	75.44	12	9	127.68	955.09	26	9	562.00	4204.1
3	8	10.559	78.99	13	0	132.73	992.91	27	0	572.56	4283.0
3	9	11.045	82.62	13	3	137.89	1031.5	27	3	853.21	4362.7
3	10	11.541	86.33	13	6	143.14	1070.8	27	6	593.96	4443.1
3	11	12.048	90.13	13	9	148.49	1110.8	27	9	604.81	4524.3
4	0	12.566	94.00	14	0	153.94	1151.5	28	0	615.75	4606.2
4	1	13.095	97.96	14	3	159.48	1193.0	28	3	626.80	4688.8
4	2	13.635	102.00	14	6	165.13	1235.3	28	6	637.94	4772.1
4	3	14.186	106.12	14	9	170.87	1278.2	28	9	649.18	4856.2
4	4	14.748	110.32	15	0	176.71	1321.9	29	0	660.52	4941.0
4	5	15.321	114.61	15	3	182.65	1366.4	29	3	671.96	5026.6
4	6	15.90	118.97	15	6	188.69	1411.5	29	6	683.49	5112.9
4	7	16.50	123.42	15	9	194.83	1457.4	29	9	695.13	5199.9
4	8	17.10	127.95	16	0	201.06	1504.1	30	0	706.86	5287.7
4	9	17.72	132.56	16	3	207.39	1551.4	30	3	718.69	5376.2
4	10	18.35	137.25	16	6	213.82	1599.5	30	6	730.62	5465.4
4	11	18.99	142.02	16	9	220.35	1648.4	30	9	742.64	5555.4
5	0	19.63	146.88	17	0	226.98	1697.9	31	0	754.77	5646.1
5	1	20.29	151.82	17	3	233.71	1748.2	31	3	766.99	5737.5
5	2	20.97	156.83	17	6	240.53	1799.3	31	6	779.31	5829.7
5	3	21.65	161.93	17	9	247.45	1851.1	31	9	791.73	5922.6
5	4	22.34	167.12	18	0	254.47	1903.6	32	0	804.25	6016.2
5	5	23.04	172.38	18	3	261.59	1956.8	32	3	816.86	6110.6
5	6	23.76	177.72	18	6	268.80	2010.8	32	6	829.58	6205.7
5	7	24.48	183.15	18	9	276.12	2065.5	32	9	842.39	6301.5

Metric Conversion Table

Arranged by C. W. Hunt, New York.

Millimeters × .03937 = inches.
Millimeters ÷ 25.4 = inches.
Centimeters × .393 = inches.
Centimeters ÷ 2.54 = inches.
Meters × 39.37 = in. (Act Cong.)
Meters × 3.28 = feet.
Meters × 1.094 = yards.
Kilometers × .621 = miles.
Kilometers ÷ 1.6093 = miles.
Kilometers × 3280.7 = feet.
Sq. Millimeters × .055 = sq. in.
Sq. Millimeters ÷ 645 = sq. in.
Sq. Centimeters × .155 = sq. in.
Sq. Centimeters ÷ 6.45 = sq. in.
Sq. Meters × 10.764 = sq. ft.
Sq. Kilometers × 247.1 = acres.
Hectars × 2.47 = acres.
Cu. Centimeters ÷ 16.387 = cu. in.
Cu. Centimeters ÷ 3.69 = fl. drs. (U. S. P.)
Cu. Centimeters ÷ 29.57 = fl. ozs. (U. S. P.)
Cu. Meters × 35.314 = cu. ft.
Cu. Meters × 1.308 = cu. yds.
Cu. Meters × 264.2 = gals. (231 cubic inches.)
Litres × 61.023 = cu. in. (Act Cong.)
Litres × 33.84 = fl. oz. (U. S. P.)
Litres × 2642 = gals. (231 cu. in.)
Litres ÷ 3.78 = gals. (231 cu. in.)
Litres ÷ 28.317 = cubic feet.
Hectolitres × 3.53 = cubic feet.
Hectolitres ÷ 2.84 = bu. (2150.42 cubic inches.)
Hectolitres × .131 = cu. yds.
Hectolitres ÷ 26.42 = gals. (231 cubic inches.)
Grammes × 15.432 = grains (Act Congress.)
Grammes ÷ 981 = dynes.
Grammes (water) ÷ 29.57 = fl. oz.
Grammes ÷ 28.35 = oz. av'pois.
Grammes per cu. cent. ÷ 27.7 = lbs. per cu. in.
Joule × .7373 = ft. pounds.
Kilo-grammes × 2.2046 = lbs.
Kilo-grammes × 35.3 = oz. avoirdupois.
Kilo-grammes ÷ 1102.3 = tons (2,000 lbs.)
Kilo-grammes per sq. cent. × 14.223 = lbs. per sq. in.
Kilo-gram meters × 7.233 = ft. lbs.
Kilo per meter × .672 = lbs. per foot.
Kilo per cubic meter × .026 = lbs. per cubic foot.
Kilo per Cheval × 2.235 = lbs. per horsepower.
Kilo-Watts × 1.35 = H. P.
Watts ÷ 746 = Horse Power.
Watts ÷ 737 = ft. lbs. per second.
Calorie × 3.968 = B. T. U.
Cheval vapeur × 98.3 = H. P.
(Centigrade) × 18 + 32 = deg. F.
Gravity Paris = 980.94 centimeters per second.

Conversion Table

Basis: 1 cubic foot of water at 39.1°F. = 62.425 pounds.
1 U. S. gallon = 231 cubic inches.
1 imperial gallon = 277.274 cubic inches.*

U. S. gallon	=	231.000000 cubic inches.
U. S. gallon	=	0.133681 cubic foot.
U. S. gallon	=	0.833111 imperial gallon.
U. S. gallon	=	3.785434 liters.
U. S. gallon of water at 39.1°F	=	8.345009 pounds.
Imperial gallon	=	277.274000 cubic inches.
Imperial gallon	=	0.160459 cubic foot.
Imperial gallon	=	1.200320 U. S. gallons.
Imperial gallon	=	4.543734 liters.
Imperial gallon of water at 39.1°F	=	10.016684 pounds.*
Cubic foot	=	7.480519 U. S. gallons.
Cubic foot	=	6.232103 imperial gallons.
Cubic foot	=	28.317016 liters.
Cubic foot of water at 39.1°F	=	62.425000 pounds.
Cubic foot of water at 39.1°F	=	0.031212 ton.
Cubic inch	=	0.004329 U. S. gallon.
Cubic inch	=	0.003607 imperial gallon.
Cubic inch	=	0.016387 liter.
Cubic inch of water at 39.1°F	=	0.036126 pound.
Cubic inch of water at 39.1°F	=	0.578009 ounce.
Pound of water at 39.1°F	=	27.681217 cubic inches.
Pound of water at 39.1°F	=	0.016019 cubic foot.
Pound of water at 39.1°F	=	0.119832 U. S. gallon.
Pound of water at 39.1°F	=	0.099833 imperial gallon.
Pound of water at 39.1°F	=	0.453617 liter.
Liter	=	0.264170 U. S. gallon.
Liter	=	0.220083 imperial gallon.
Liter	=	61.023378 cubic inches.
Liter	=	0.035314 cubic foot.
Liter of water at 39.1°F	=	2.204505 pounds.

*The British imperial gallon is usually defined as being equal to 277.274 cubic inches, or 10 pounds of pure water at the temperature of 62°F. when the barometer is at 30 inches.

Useful Factors

Inches	×	0.08333	= feet
Inches	×	0.02778	= yards
Inches	×	0.00001578	= miles
Square inches	×	0.00695	= square feet
Square inches	×	0.0007716	= square yards
Cubic inches	×	0.00058	= cubic feet
Cubic inches	×	0.0000214	= cubic yards
Cubic inches	×	0.004329	= U. S. gallons
Feet	×	0.334	= yards
Feet	×	0.00019	= miles
Square feet	×	144.00	= square inches
Square feet	×	0.1112	= square yards
Cubic feet	×	1728.00	= cubic inches
Cubic feet	×	0.03704	= cubic yards
Cubic feet	×	7.48	= U. S. gallons
Yards	×	36.000	= inches
Yards	×	3.000	= feet
Yards	×	0.0005681	= miles
Square yards	×	1296.000	= square inches
Square yards	×	9.000	= square feet
Cubic yards	×	46656.000	= cubic inches
Cubic yards	×	27.000	= cubic feet
Miles	×	63360.000	= inches
Miles	×	5280.000	= feet
Miles	×	1760.000	= yards
Avoirdupois ounces	×	0.0625	= pounds
Avoirdupois ounces	×	0.00003125	= tons
Avoirdupois pounds	×	16.000	= ounces
Avoirdupois pounds	×	.01	= hundredweight
Avoirdupois pounds	×	0.0005	= tons
Avoirdupois pounds	×	27.681	= cu. in wat. at 39.2°F.
Avoirdupois tons	×	32000.00	= ounces
Avoirdupois tons	×	2000.00	= pounds
Horsepower	×	746.00	= Watts
Watts	×	0.00134	= horsepower

Useful Factors—Continued

Cubic feet (of water) (39.1°)	×	62.425	= pounds
Cubic feet (of water) (39.1°)	×	7.48	= U. S. gallons
Cubic feet (of water) (39.1°)	×	6.232	= English gallons
Cubic feet (of water) (39.1°)	×	0.028	= tons
Cubic foot of ice	×	57.2	= pounds
Cubic inches of water (39.1°)	×	0.036024	= pounds
Cubic inches of water (39.1°)	×	0.004329	= U. S. gallons
Cubic inches of water (39.1°)	×	0.003607	= English gallons
Cubic inches of water (39.1°)	×	0.576384	= ounces
Pounds of water	×	27.72	= cubic inches
Pounds of water	×	0.01602	= cubic feet
Pounds of water	×	0.083	= U. S. gallons
Pounds of water	×	0.10	= English gallons
Tons of water	×	268.80	= U. S. gallons
Tons of water	×	224.00	= English gallons
Tons of water	×	35.90	= cubic feet
Ounces of water	×	1.735	= cubic inches

A column of water 1 inch square by 1 foot high weighs 0.434 pounds.

A column of water 1 inch square by 2.31 feet high weighs 1 pound.

Water is at its greatest density at 39.2° F.

Sea water is 1.6 to 1.9 heavier than fresh.

One cubic inch of water makes approximately 1 cubic foot of steam at atmospheric pressure.

27222 cubic feet of steam at atmospheric pressure weighs 1 pound.

Weight of round iron per foot = square of diameter in quarter inches ÷ 6.

Weight of flat iron per foot = width × thickness × 10.3.

Weight of flat plates per square foot = 5 pounds for each ⅛-inch thickness.

Weight of chain = diameter squared × 10.7 (approximately).

Safe load (in pounds) for chains = square of quarter inches in diameter of bar.

Water Factors

U. S. gallons	×	8.33	= pounds
U. S. gallons	×	0.13368	= cubic feet
U. S. gallons	×	231.00	= cubic inches
U. S. gallons	×	0.83	= English gallons
U. S. gallons	×	3.78	= litres
English gallons (Imperial)	×	10	= pounds
English gallons (Imperial)	×	0.16	= cubic feet
English gallons (Imperial)	×	277.274	= cubic inches
English gallons (Imperial)	×	1.2	= U. S. gallons
English gallons (Imperial)	×	4.537	= litres

Useful Information

To find circumference of a circle multiply diameter by 3.1416.

To find diameter of a circle multiply circumference by .3183.

To find area of a circle multiply square of diameter by .7854.

To find surface of a ball multiply square of diameter by 3.1416.

To find side of an equal square multiply diameter by .8862.

To find cubic inches in a ball multiply cube of diameter by .5236.

Doubling the diameter of a pipe increases its capacity four times.

A gallon of water (U. S. standard) weighs 8⅓ lbs. and contains 231 cubic inches.

A cubic foot of water contains 7.48 gallons, 1728 cubic inches, and weighs 62.4 lbs.

To find the pressure in pounds per square inch of a column of water multiply the height of the column in feet by .434.

A standard horsepower: The evaporation of 30 lbs. of water per hour from a feed-water temperature of 100° F. into steam at 70 lbs. gauge pressure. One horsepower is the power required to raise 33,000 lbs. one foot in one minute.

Equals 33,000 foot-pounds per minute
" 1,980,000 " " hour

To find the horsepower of an engine multiply the piston speed in feet per minute by the area of the piston in square inches and by the mean effective pressure, then divide by 33,000.

Each nominal horsepower in boilers requires one cubic foot of water per hour.

In calculating horsepower of tubular boilers, consider 12 square feet of heating surface equal to one nominal horsepower.

To find capacity of tanks any size; given dimensions of a cylinder in inches, to find its capacity in U. S. gallons:

Square the diameter, multiply by the length and by .0034

Useful Information—Continued

To approximately ascertain heating surface in tubular boilers multiply ⅔ the circumference of boiler by length of boiler in inches and add to it the area of all the tubes.

When designing boilers the T. S. is specified, the factor of safety, diameter and pressure per square inch are decided upon, and the only quantities remaining unknown are the thickness and the efficiency of the joint.

Let P = pressure of steam in pounds per square inch.
T = thickness of plate in shell.
E = efficiency of joints in shell.
D = diameter of shell.
S_1 = ultimate strength of material.
F = factor of safety.

Solving the equation $\frac{D \times P \times F}{2\ S_1} = T \times E$

or $\frac{D \times P \times F}{2\ S_1 \times E} = T$

Pressure allowable for concaved heads of boilers: Multiply the pressure per square inch allowable for bumped heads attached to boilers or drums convexly by the constant .6, and the product will give the pressure per square inch allowable in concaved heads.—*U. S. Gov. Rule II, Par. 12.*

To find the amount of air that can be produced by different size air cylinders: Find the area of the cylinder and multiply that by the stroke; then multiply result by 2 if it is a Straight Line Compressor; by 4 if a Duplex Compressor; or by 2 if Compound Duplex Compressor. Divide this result by 1728, which will give amount of air per stroke and then multiply by number of strokes per minute.

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